Lecture 1: Introduction to mycology

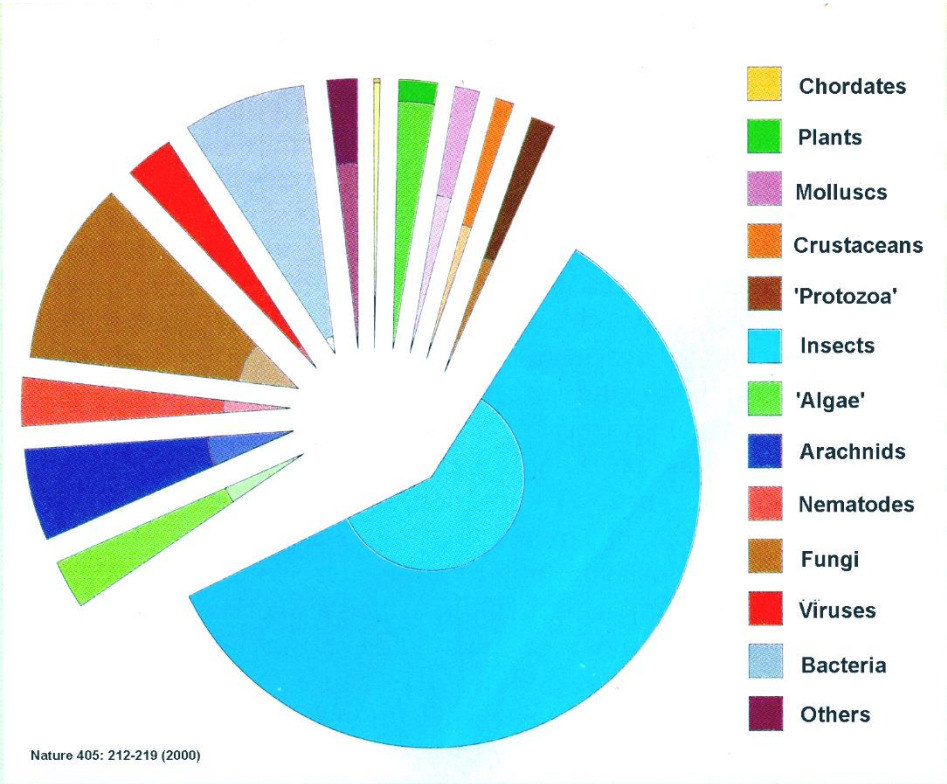
Definitions:

What is mycology? Mycology is the study of fungi and their multiple functions in nature.

What are fungi: Fungi are eukaryotic organisms that do not contain chlorophyll, but have cell walls, filamentous structures, and produce spores. These organisms grow as saprophytes and decompose dead organic matter also as pathogens of plants, animals and humans, and in food spoilage and as producers of secondary metabolites.

Why study fungi?

Fungi are among the most diverse organisms on Earth, and are considered only second to the Insects in species diversity. There are between 100,000 to 200,000 species depending on how they are classified. About 300 species are presently known to be pathogenic for human.



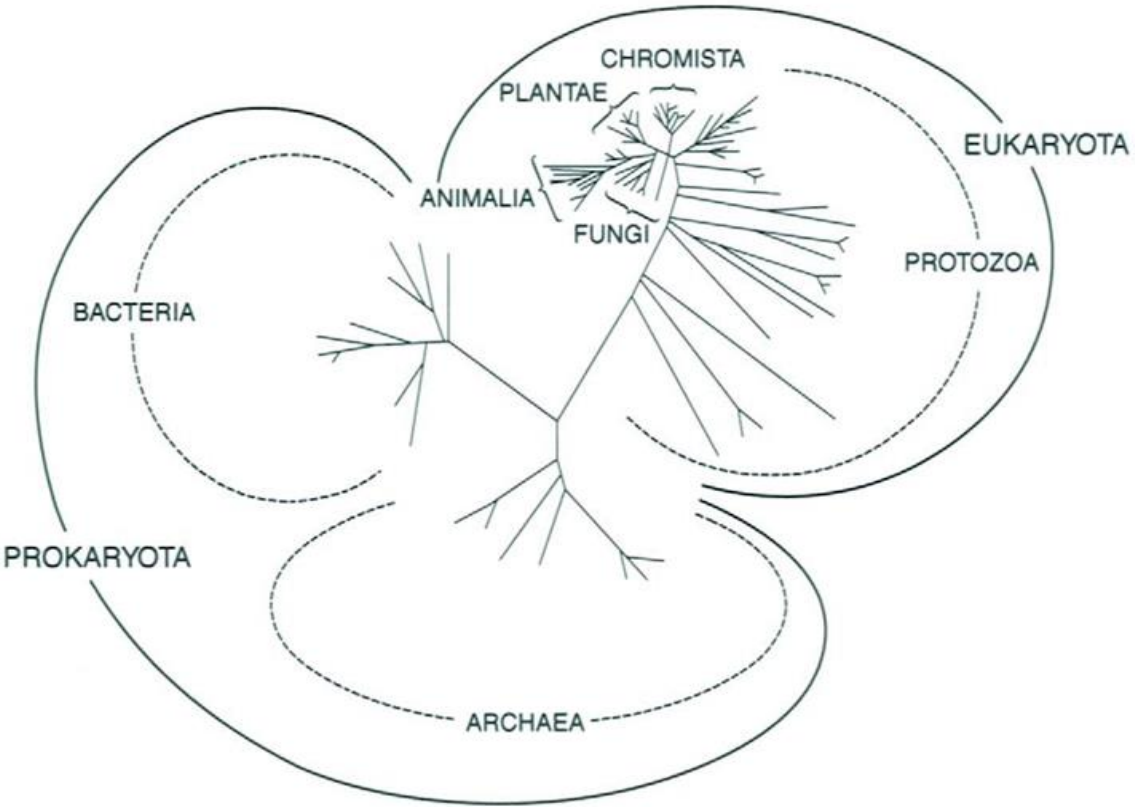
Mycology (from Greek term μύκης (mykes, mukos) "fungus" and logy "science"

According to Whittaker 1969; there are five kingdoms of living things, and the fungi are in the Kingdom Mycetae.

Kingdom	Characteristic	Example
Monera	Prokaryote	Bacteria Actinomycetes
Protista	Eukaryote	protozoa
Mycetae	Eukaryocyte	fungi
Plantae	Eukaryocyte	Plants Moss
Animalae	Eukaryocyte	Arthropods Human Mammals Birds

The taxonomy of the Kingdom Fungi is evolving and is controversial. Formerly based on gross and light microscopic morphology, studies of ultra-structure, biochemistry and molecular biology provide new evidence on which to base taxonomic positions

According to Carlile *et al.*, 2001; fungi are recognized as one of five Eucaryotic kingdoms including Animalae, Plantae, Chromista (straminopila) and Protozoa.



A phylogenetic tree showing the relationships between the two Prokaryote and five Eukaryote kingdoms (Carlile *et al.*, 2001)

Characteristics of fungi:

1. Nutrition: Heterotrophic (lacking photosynthesis), feeding by absorption rather than Ingestion except slime molds.

2. Vegetative state: On or in the substratum, typically as a non-motile mycelium of hyphae showing internal protoplasmic streaming. Motile reproductive states may occur.

3. Cell wall: Typically present, usually based on β-glucans and chitin, rarely on glucans and cellulose (Oomycota).

4. Nuclear status: Eukaryotic, uni- or multinucleate, the thallus being homo- or heterokaryotic, haploid, dikaryotic or diploid, the latter usually of short duration (but exceptions are known from several taxonomic groups).

5. Life cycle: Simple or, more usually, complex.

6. Reproduction: The following reproductive events may occur: sexual (i.e. nuclear fusion and meiosis) and/or Parasexual (i.e. involving nuclear fusion followed by gradual de-diploidization) and/or asexual (i.e. purely mitotic nuclear division).

7. Propagules: These are typically microscopically small spores produced in high numbers. Motile spores are confined to certain groups.

8. Sporocarps: Microscopic or macroscopic and showing characteristic shapes but only limited tissue differentiation.

9. Habitat: Ubiquitous in terrestrial and freshwater habitats, less so in the marine environment.

10. Ecology: Important ecological roles as saprotrophs, mutualistic symbionts, parasites, or hyperparasites.

11. Distribution: Cosmopolitan , fungi are among the most diverse organisms on earth and are considered only second to the insects in species diversity.

Importance of Fungi:

1- Fungi are the agents responsible for much of the disintegration of organic matter and such they affect us directly by destroying food, fabrics, leather and other consumer goods manufactured from materials subject to fungal attack.

2- They are the basis of a number of industrial processes involving fermentation, such as making of bread example: ***Saccharomyces cervisae***, wines, beers, and the fermentation of cacao, bean and the preparation of certain cheeses.

3- Production of many organic acids of some drugs such as Ergotamine and cortisone and some vitamin preparations, and are responsible for manufacture of a number of antibiotics, notably Penicillin and Cephalosporin .

4- Some of them are good for human consumer such as ***Agaricus bisporus*** - edible mushroom, and single cell proteins.

5-As saprotrophs, particularly as decomposers, fungi are essential components of the carbon cycle and are among the few organisms that can break down lignin. Many fungi are particularly important in the decomposition of plant debris because of their ability to utilize cellulose such as ***Xylaria***

6- Fungi form symbiotic relationships with a number of organisms: **Lichens** , **Mycorrhizas** and **Endophytes**

7- Use it as important research tools in cytologists, Geneticists, and biochemists such as ***Neurospora***.

8- Over 70% of all plant diseases are caused by They cause majority of known plant disease such as ***Botrytis***, and many diseases of animals and humans such as ***Fusarium***.

History of mycology:

Mycology is a relatively new science that became systematic after the development of the microscope in the 16th century.

*Fungal spores were first observed by **Giambattista della Porta in 1588**,

*The seminal work in the development of mycology is considered to be the publication of **Pier Antonio Micheli's 1729** work Nova plantarum genera. Micheli not only observed spores but also showed that, under the proper conditions, they could be induced into growing into the same species of fungi from which they originated.

*Extending the use of the binomial system of nomenclature introduced by **Carl Linnaeus** in Species plantarum .

***Hendrik Persoon (1761–1836)** established the first classification of mushrooms with such skill so as to be considered a founder of modern mycology.

***Elias Magnus Fries (1794–1878)** further elaborated the classification of fungi, using spore color and various microscopic characteristics, methods still used by taxonomists today.

***Anton de Bary(1861)** established modern mycology ; he studied slime molds, rusts and late blight of potato diseases.

***Berfield(1875)** studied smut disease and he used copper sulphate to control plant diseases caused by fungi.

*** Robert Koch (1843-1910)** the first one who discovered artificial medium to isolate and growth fungi.

The 20th century has seen a modernization of mycology.

Principles of living fungi

Living mode of fungi :

In nature fungi obtain their food either by infecting living organisms as parasites or by attacking dead organic matter as saprobes, many also form symbiotic relationships with higher plants as in mycorrhiza (Ectotrophic in **glomeromycetes fungi** and Endotrophic) and with blue green algae as in Lichens, example: **foliose lichen**.

Fungi that live on dead matter and incapable of infecting living organisms are called (obligate saprobes example ***Mucor***); those capable of causing disease or of living on dead organic matter (facultative parasites (or) facultative saprobes: leaf curl fungi example ***Taphrina deformans***); and those that can't live except on living protoplasm, (obligate parasites such as **downy and powdery mildews**). A living organisms infected by parasite is known as the host.

Cultivation of fungi :

Fungi which we can cultivated them on nutrient media are (saprobes and facultative parasites), and those fungi cultivate on different culture media such as:

1. Natural media: They are plant extract such as wheat extract, potato extract, carrot and others vegetable extract, also we can use fruit to prepare this kind of media.

2. Synthetic media: The main compositions of this medium are certain chemicals and some salts such as Czapek`s Dox Medium .

3. Semi synthetic media: they are mixed of two kinds of media (natural and synthetic) such as Potato Dextrose Media.

These three types of culture media are liquid so we can solidified them by adding **(1.5 – 2.0 %)** agar.

Optimum conditions suitable for fungal growth :

1. Temperature: Fungi are living in wide range of temperature and according to it, fungi classified in to :

A. Mesophilic fungi: The range is (10–40ºC) and the optimum is (25 – 35ºC)

B. **Psychrophilic fungi**: The range is (5–25ºC) and the optimum is (15ºC) **C**. **Thermophilic fungi**: The range is (20 – 50ºC) and the optimum is (40ºC)
2. Light: In some species the pigment melanin may play a role in extracting energy from ionizing radiation, such as gamma radiation. This form of "radiotrophic" growth has been described for only a few species, the effects on growth rates are small, and the underlying biophysical and biochemical processes are not well known
3-Aeration: All fungi prefer living in aerobic condition
4- Hydrogen Ion concentration: pH: (acidic).

5. Humidity:
A) Some fungi are water mold.
B) Some fungi need some water for growth.
C) Some fungi are capable to growth in near-dry condition.

What are the important elements for fungal growth?

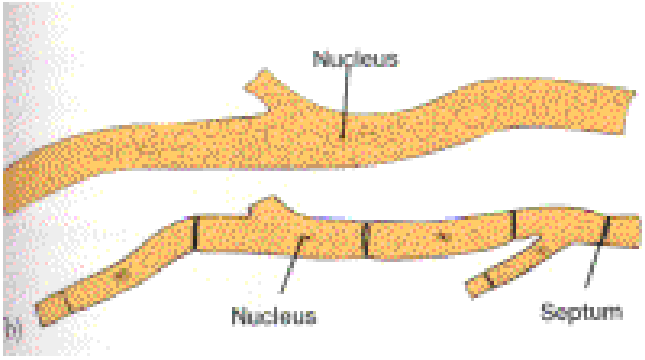
1. Carbon sources: (carbohydrates) such as mono sugar (glucose and fructose) or di sugar such as sucrose and maltose and multi sugars such as starch .
2. Nitrogen sources:
A. Organic source: such as Amino acids and peptone.
B. In organic source: such as nitrate and ammonia.
The salts are added according to fungi requirements.
A. Macro elements: which add in large quantities such as Na, Mg, k, Zn.
B. Micro elements: which add in trace quantities such as Sc , Mn.

Lecture 2: Morphology of fungi

Morphology of fungi

When fungi are grown on suitable medium, produce long, branching filaments, those called -Mold- . Each filament is called hyphae. Hyphae are long, slender transparent, wall filled or lined with a large of protoplasm varying in thickness. Generally 3-10 microns in diameter. If hyphae have cross wall, the fungus is said to be

septate- if not -aseptate-(coenocytic hyphae).



Aseptate (or coenocytic) and septate hyphae

The presence or absence of these cross wall can be important in differentiating between certain classes. Hyphae may become divided into a chain of cells by the formation of septa (septum). As the hyphae continue to growth and branched a mat of growth called mycelium. The part of growth which project above the surface of substrate called aerial mycelium- which hold the spores-. The part which penetrate into the substrate and absorbs food is known vegetative mycelium.

The mycelium of parasitic fungi grows either by spreading between the cells or penetrating into them. The mycelium of fungus generally beings as a short-germ-tube emerging from a germinating spore. Fungal colony tend to be circular in out-line on solid medium, while the mycelium has a tendency to grow more or less equally in all

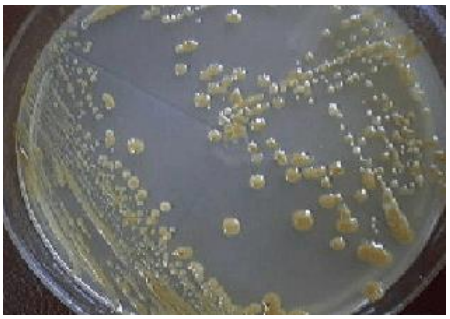
directions from central point, and to develop colony- you can observe this by growing certain fungi on liquid and solid media.

A: Somatic phase (Soma)

Fungi can be classified into four groups according to their morphology:

1- **Mold – Mould** - : Which grow as branching filaments - hyphae - and produce the mycelium, while in slime molds the somatic phase grow as plasmodium .
2- **Yeast**: are eukaryotic, single-celled microorganisms (Unicellular cells) which appears as round cells, do not form spores but reproduce by budding of the parent cells. This process of budding results in the production of two cells. Most are single celled structure with a thick cell wall such as *Cryptococcus neoformans*. **Note:** The word "yeast" comes from Old English *gist*, *gyst*, and from the Indo-European root *yes-*, meaning "boil", "foam", or "bubble.
3- **Yeast-like fungi**: Also reproduce by budding and grow as non branching filament-pseudo hyphae- such as *Candida albicans.*
4- **Dimorphic fungi:** They grow as yeast form in tissue when incubated at 37ºC in vitro, but when incubated at 22ºC grow as mycelium form. This group of fungi have two phases of growth – Dimorphic such as :-*Histoplasma capsulatum ; Blastomyces dermatitidis*

Molds growing on a solid medium



Yeast growing on a solid medium

Plasmodium (of slime mold)

Hyphal Aggregation and Modifications in Fungi

In majority of fungi, hyphae are simple. But, in some advanced fungi, hyphae may undergo certain modification in response to functional needs. Hyphal modifications are hyphal aggregations are required to do specific functions during the life cycle of fungi Important hyphal modifications in fungi are:

(1). Prosenchyma
(2). Pseudoparenchyma
(3). Sclerotia (Sclerotium)
(4). Rhizomorphs (Mycelial cords)
(5). Appressoria (Appressorium)
(6). Haustoria (Haustorium)
(7). Stroma (stromata)
(8). Snares (hyphal traps)
(9). Rhizoides
(10). Clampconnection

1. **Prosenchyma (**Plectenchyma or Proso-plectenchyma)
It is formed by the loosely packed tissue like organization of fungi and is formed when the component hyphae is arranged more or less parallel to one another and the whole mass become a felt like structure. ex: ***Claviceps pururea***
2. **Pseudoparenchyma**

hyphae are closely intertwined and forms a tissue like structure in cross section and the hyphae lose their individuality and they are not distinguishable from each other. ex: higher fungi.

3. **Rhizomorphs**

Rhizomorphs (mycelial cords) are thick strands or root like aggregation of somatic hyphae in some fungi, gelatinous, dark brown and rope like coiled structures. the intertwining of hyphae is too tight so that hyphae loose its individuality. Individual hyphae are arranged in parallel way They are perennating structures with high penetration and survive for many years and they give rise new mycelia in the favourable conditions. Ex: ***Armillariella mellea.***

4. **Sclerotia**

Sclerotium is a compact dark brown with inner cells are colourless globose structure formed by the aggregation of hyphae in some fungi. The interwoven hyphae are very much compact so that the individuality of hyphae is lost and the mass become rounded and cushion like structures. Sclerotium survives for long periods, sometimes for many years and they represent the resting stage of some fungi. They accumulate food materials and helps in vegetative reproduction. Ex:***Rhizoctonia solani***.

5. Appressorium

Appressorium is a terminal simple or lobed swollen structure of germ tubes on infecting hyphae**,** It adheres to the surface of host and help in the penetrating of hyphae**.** The infection peg is originated from the appressorium, ex: ***Erysiphae***

6. Haustorium

Is the intracellular absorbing knob like, elongated, finger like or branched structure of obligate parasites , it is the meant for absorbing food materials from the host tissue and They secrete some special enzymes which help in hydrolyzing proteins and carbohydrates of host, ex : ***Albugo***

7. Stroma

Stroma are compact somatic structures, They are flat cushion like pseudoparenchymatous structures and the fructifications are usually found on or in them.

8. Snares

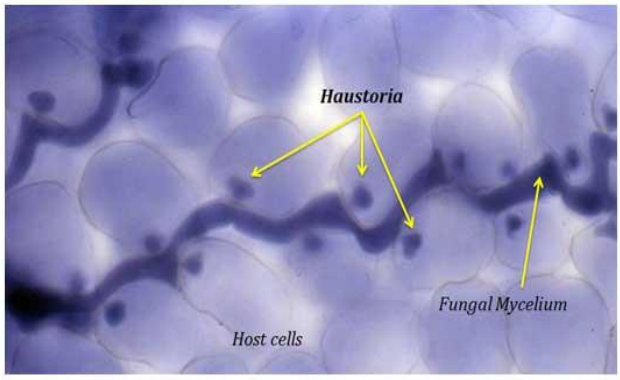
Snares are trap like structures produced by predaceous fungi to capture small animals such nematodes and protozons.

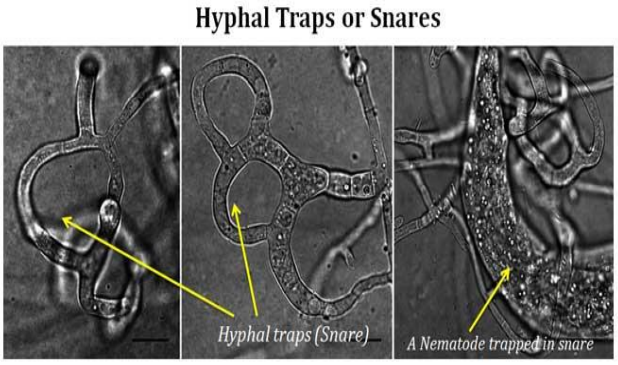
9. Rhizoides

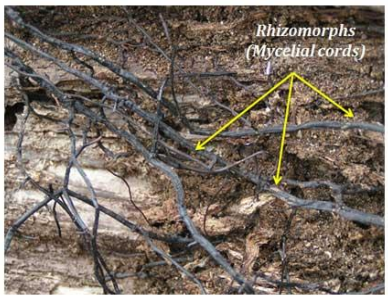
a short, thin filament, resembles a root that anchors the growing (vegetative) body to a substratum and that is capable of absorbing nutrients. It may serve either as a feeding organ (*in* ***Rhizopus***) or to anchor the thallus to its substratum *(* ***in Chytridium***).

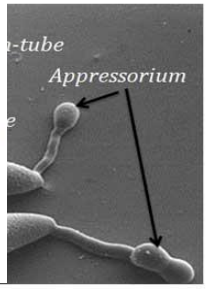
10. Clamp connection:

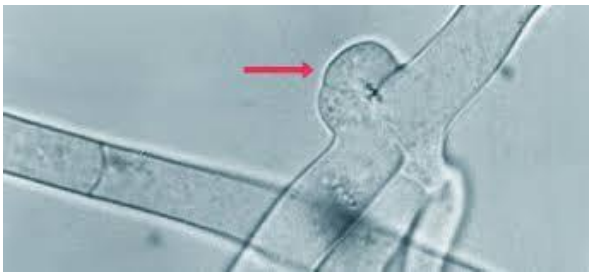
A bridge like hyphal connection characteristics of the secondary mycelium of many Basidiomycota; involved in maintaining the dikaryotic condition.











Clamp

B: Sporocarp (Fruiting body) and spores

In fungi, the sporocarp (also known as fruit body or fruitbody) is a multicellular structure on which spore-producing structures, such as basidia or asci, are borne. The

fruitbody is part of the sexual phase of a fungal life cycle, with the rest of the life cycle being characterized by vegetative mycelial growth and asexual spore production. the sporocarp of a basidiomycota is known as a basidiocarp or basidium, while the fruitbody of an ascomycota is known as an ascocarp. Many shapes and morphologies are found in both basidiocarps and ascocarps: these features play an important role in the identification and taxonomy of fungi.

The sexual fruiting bodies are:

Basidium: In fungi a basidiocarp, basidium or basidioma (plural: basidiomata) is the sporocarp of a basidiomycota, the multicellular structure on which the spore-producing hymenium is borne. All basidiocarps serve as the structure on which the hymenium is produced. Basidia are found on the surface of the hymenium, and the basidia ultimately produce spores. In its simplest form, a basidiocarp consists of an undifferentiated fruiting structure with a hymenium on the surface; such a structure is characteristic of many simple jelly and club fungi. In more complex basidiocarps, there is differentiation into a stipe, a pileus, and/or various types of hymenophores.

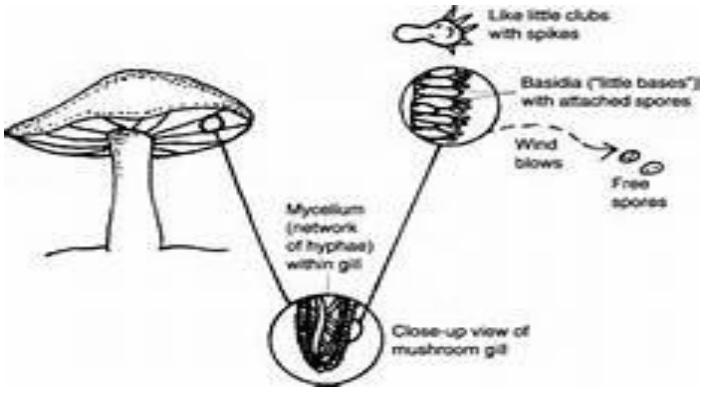
Apothecium: is a wide, open, saucer-shaped or cup-shaped fruit body. It is sessile and fleshy. The structure of the apothecium chiefly consists of three parts: hymenium (upper concave surface).

Cleistothecium : is a globose, completely closed fruit body with no special opening to the outside. The ascomatal wall is called peridium and typically consists of densely interwoven hyphae or pseudoparenchyma cells.

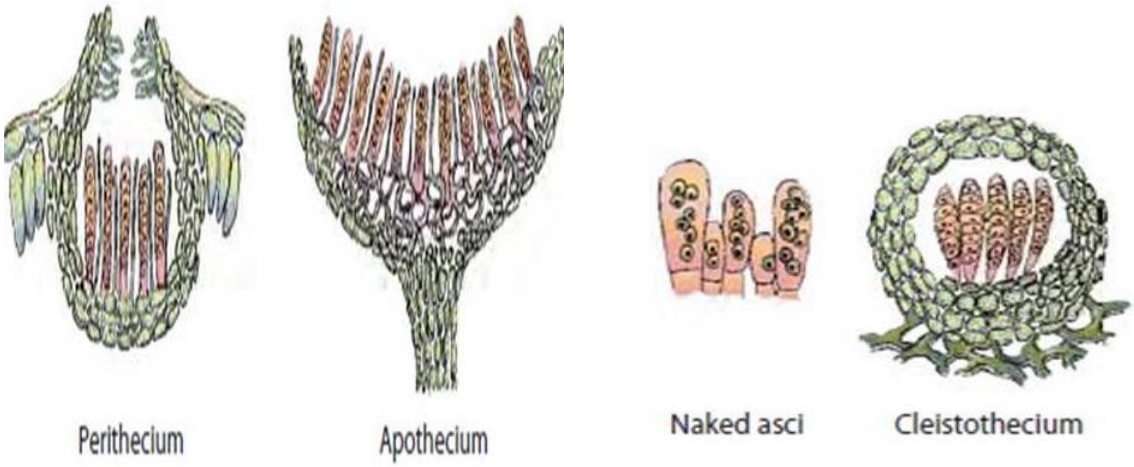
Gymnothecium : similar to a cleistothecium, a gymnothecium is a completely enclosed structure containing globose or pear-shaped, deliquescent asci. However, unlike the cleistothecium, the peridial wall of a gymnothecium consists of a loosely woven "tuft" of hyphae, often ornamented with elaborate coils or spines. examples are the *Gymnoascus, Talaromyces* and the dermatophyte *Arthroderma*.

Perithecium: a flask shaped structure opening by a pore or ostiole (short papilla opening by a circular pore) through which the ascospores escape. The ostiolar canal may be lined by hair-like structures called periphyses. The unitunicate asci are usually cylindrical in shape, borne on a stipe (stalk), released from a pore, developed from the inner wall of the perithecium and arise from a basal plectenchyma-centrum. Examples are members of Sphaeriales and Hypocreales. Perithecia are also found in *Xylaria* and *Nectria.*

Pseudothecium (ascostroma): This is similar to a perithecium, but the asci are not regularly organised into a hymenium and they are bitunicate, having a double wall that expands when it takes up water and shoots the enclosed spores out suddenly to disperse them. Example species are Apple scab (*Venturia inaequalis*) and the horse chestnut disease Guignardia aesculi.



Basidium

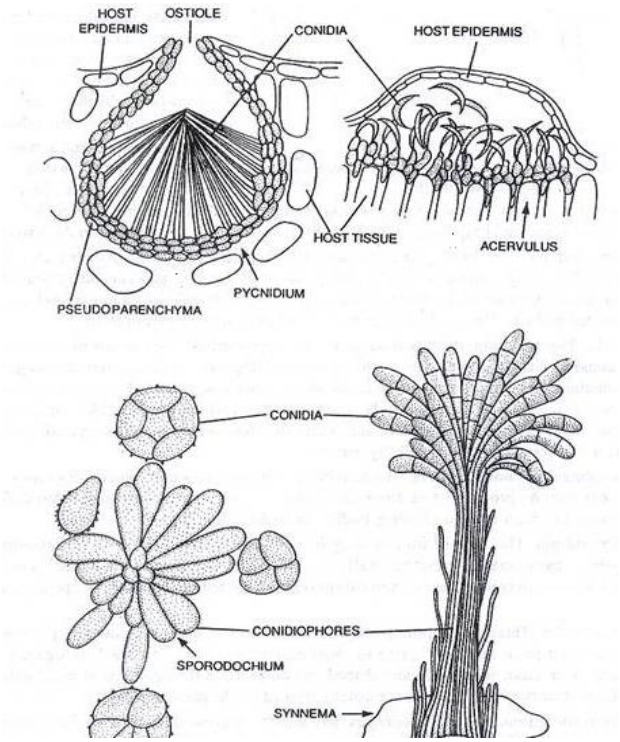


The sexual fruiting bodies In ascomycota

In imperfect fungi (Deutromycetes), the Sporocarps are Pycnidium: a flask-shaped, globose or oval-shaped structure that looks like a cleistothecium or a perithecium but has a cavity filled with conidiophores and conidia instead of asci- and ascospores and often identified incorrectly as an ascocarp. Acervulus : functionally a structure similar to a pycnidium, but structurally different by being formed by hyphae of plant pathogenic fungi in association with plant tissue and often appears to be a pustule formed just under plant epidermis, which erupts and exudes conidia. Sporodochium: large mass of short conidiophores and hyphae which arise together from the surface of a structure (multihyphal aggregate) called a stroma (stromata).

A synnema : derivation: Threads together) is a large, erect reproductive structure borne by some **fungi**, bearing compact **conidiophores**,[1]which fuse together to form a strand resembling a stalk of wheat, with conidia at the end or on the edges, ex: *Aspergillus caelatus* .

A Sporodochium: is a small, compact **stroma** (mass of **hyphae**) usually formed on host plants **parasitised** by mitosporic **fungi** of the form **order Tuberculariales** (**sub -division Deuteromycota**).This stroma bears the **conidiophores** on which



Sporocarps of imperfect fungi (Deutromycetes)

Sporophores and Spores

when the mycelium of a fungus reaches a certain stage of growth, it begins to produce spores either directly on the somatic hyphae or, more often, on special sporiferous (spore-producing) hyphae, which may be loosely arranged or grouped into intricate structures called fruiting bodies, or sporophores.

1- Asexual spores:- Which occurs by the process of mitosis. This is most common process by which spores are reproduced in fungi.

There are four types of medically important:

a- Blastospores: The type of spore develop by budding.

b- Chlamydospores: In some fungi the hyphal cell become specialized spore when the cell enlarged and develop thick walls

c- Arthrospores: Other hyphal cells break apart and produce arthrospores. Fragmentation may also happen naturally by the action of wind, soil movement or insects.

d- Conidia: A conidium is produced on a specialized structure called conidiophore. A spore which is produced directly on a hyphae or hyphal tips is called Aleuriospore, when a fungus produce two sizes of aleuriospores : The large one is called Macro-aleuriospore., The smaller one is called Micro- aleuriospore.

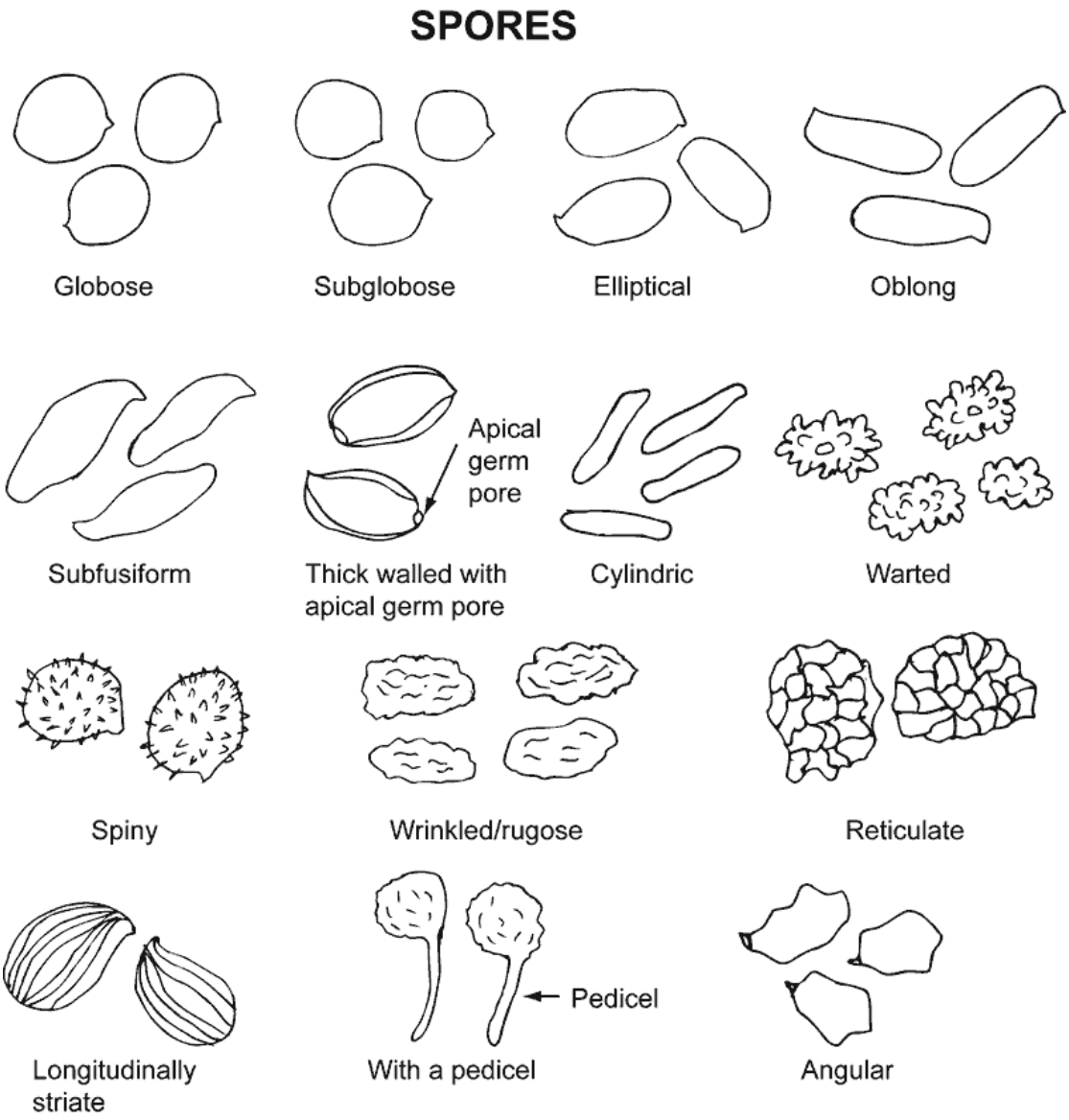
2- Sexual spores: Reproduce by meiosis

a- Ascospores: Usually 4-8 spores found in a cell called ascus- asci.

b- Basidiospores: Usually 4- spores found in the surface of cell called basidium.

c- Zygosopores: Large-thick walled spore formed on hyphae.

d- Oospores: This type of spore formed inside cell called Oogonium.



Microscopic features of spores

Lecture 3: Fungal cell Structure and Function

Overview of the Hypha

- The hypha is a rigid tube containing cytoplasm. Growth occurs at the tips of hyphae. Behind the tip, the cell is aging.
- Many hyphae possess septa. Septa contain pores through which cytoplasm flows and Hyphae are actually interconnected compartments, not individual cells.
- Cell wall of hyphae are complex in structure and composition,thinner at apical (growing) end, Plasma membrane closely associated with inner portion of the wall.

Fungal Ultrastructure

- Zonation of organelles in hyphae
- Hyphae show a defined polarity in the arrangement of organelles
- Apical tip
- Extreme end - no organelles, but numerous membrane-bound vesicles of differing
- electron densities (Golgi derived?), cell wall is dynamic and rather 'plastic' (site of synthesis)
- Chitin synthase is present
- Apical vesicle cluster (AVC) - Spitzenkörper
- Actin microfilaments
- Apical tip (cont.)
- Short zone following apex - no organelles, but rich in mitochondria
- Nuclei - distribution varies
- Sub-apical regions contain a diverse array of organelles, septa are present, and the cell walls are less dynamic, more rigid in structure
- **Yeast ultrastructure**

❖ Typical cellular structures of a yeast include those found in other eukaryotes

- ❖ Reproduction by budding does impact the structure of the cell wall producing
  - o Bud scars on the mother cell
  - o Birth scars on the newly-formed daughter cell

Fungal Cell Wall

Functions

- o Structural barrier
- o Determines pattern of cell growth and is partly dependent upon:

- Chemical composition

- Assembly of the wall components

- o Environmental interface of the fungus

-Protects against osmotic lysis

-Acts as a molecular sieve

-Contains pigments for protection

- o Binding site for enzymes
- o Mediates interactions with other organisms

Cell wall components

- o Two major types of components

- Structural polymers - polysaccharide fibrils that provide rigidity/integrity of the wall

- Matrix components - cross-link the fibrils as well as coat/embed them

- o Main wall **components differ between the major taxonomic groups of fungi**

- Chitin - straight chain polymers of b-1,4-linked N-acetyl glucosamine residues;

- chitosan is de-acetylated chitin

- Glucan - polymers of b-1,3-linked glucose residues with short b-1,6-linked side chains

- Cellulose - b-1,4-linked glucans.

- Matrix polymers: Glucouronic acids, Mannoproteins - mannose attached to protein.

- **Wall architecture**

- Hyphae tend to have separate layers of wall components
- Layers actually grade into one another
- Components of one layer tend to be covalently bond to those of another
- Subapical regions are relatively thicker than apical region
- Yeasts have less complex wall architecture

Extrahyphal matrix - two types:

- Defined zone of polysaccharide - capsule
- Diffuse area outside hyphal wall

Septa

- Septa occur at generally regular intervals along a length of a hypha
- Perforations allow cytoplasm to flow from one cell to another
- When a cell is damaged, a Woronin body or coagulated cytoplasm serves a plug to prevent loss of cytoplasm
- Coenocytic fungi are more susceptible to cellular damage

Functions of septa

- Structural support of the hypha.
- Enables differentiation by dividing hypha into different cells that can undergo separate modes of development.

Types of septa

- Simple
- Dolipore

Fungal Nucleus

- Double membrane bound organelle ranging in size from 1-2 μm to 20-25 μm in diameter
- Unique features of fungal nucleus

- Membrane remains intact during mitosis
- No clear metaphase plate
- Various types of spindle-pole bodies (microtubule-organizing centers) depending upon species

- **Ploidy**

-Most fungi are haploid with the number of chromosomes ranging from 6 to 20

-Some fungi are naturally diploid

-Others alternate between haploid and diploid states

Possible reasons for haploidy:

-Multiple haploid nuclei can mask mutations

-Advantageous mutations can be selected

Cytoplasmic Organelles

- Plasma membrane - phospholipid bilayer

- Involved in uptake of nutrients

-Anchorage for enzymes/proteins, e.g., chitin synthase, glucan synthase, etc.

-Signal transduction

-Differs in that it contains ergosterol

*****Site of action for certain antifungal drugs

*****Oomycota contain plant-like sterols

Secretory system

- Consists of the following:

- Endoplasmic reticulum (ER)
-Golgi apparatus (or equivalent) - different in than those found in animals, plants, and the Oomycota in that they lack cisternae
- Membrane-bound vesicles
  - Involved in fungal tip growth
  - Commercially important in the production of extracellular products

Chitosomes- microvesicles that are capable of synthesizing chitin

- First noted from homogenized hyphae
- Able to self assemble

- Controversial as to whether or not they are an integral part of the plasma membrane
- Function primarily within the region of the apical tip

Vacuoles

- **Functions**

-Storage

-Recycling of materials

-Contain proteolytic enzymes

-Regulation of cellular pH

-Possible role in cellular expansion/growth

- **Shape**

-Round

-Tubular - may be involved in material transport

Endocytosis and vesicle trafficking - data is still unclear if fungi have an endosomal system: like that found in other types of eukaryotes

Fungal Cytoskeleton

- Cytoskeleton functions:

-Transport of organelles

-Cytoplasmic streaming

-Chromosome separation

- Three types of cytoskeletal filaments:

- Microtubules - composed of tubulin

-Microfilaments - composed of actin

- Intermediate filaments - provide tensil strength

- All play a major role in hyphal tip growth

Lecture 4: Reproduction of fungi

Reproduction is the formation of new individuals having all the characteristics typical of the species. Two general types of reproduction are recognized: Sexual and asexual. Asexual reproduction sometimes called somatic or vegetative, does not involve the union of nuclei sex cells or sex organs. Sexual reproduction on the other hand, is characterized by union of two nuclei.

In the formation of reproductive organs, either sexual or asexual, the entire thallus may be converted into one or more reproductive structure, so that somatic and reproductive phases do not occur together in the same individual, fungi that follow this pattern are called (Holocarpic) . In the maturity of fungi, however the reproductive organs arise from only a portion of the thallus, while the remainder continuous its normal somatic activities, the fungi in this category are called (Eucarpic).

Asexual Reproduction

In general, asexual reproduction is more important for the propagation of the species because it results in the production of numerous individuals, and particularly since the asexual cycle is usually repeated several times during the season, whereas the sexual stage of many fungi is produced only once a year.

The asexual methods of reproduction commonly found in fungi may be summarized as follows

1) Fragmentation

Each fragment growing into a new individual. Some fungi employ fragmentation of hyphae as a normal means of propagation. The hyphae may break up into their component cells that behave as spore. These spores are known as **arthrospores**. If the cells become enveloped in a thick wall before the separate from each other or from other hyphal cell, they are often called **chlamydospores**. Fragmentation may also occur accidentally by the tearing off of parts of the mycelium through external forces. Such pits of mycelium under favorable conditions will start a new employ mycelia fragmentation to keep fungal cultures growing on artificial media by transferring a bit of mycelium to fresh media and thus starting a new colony.

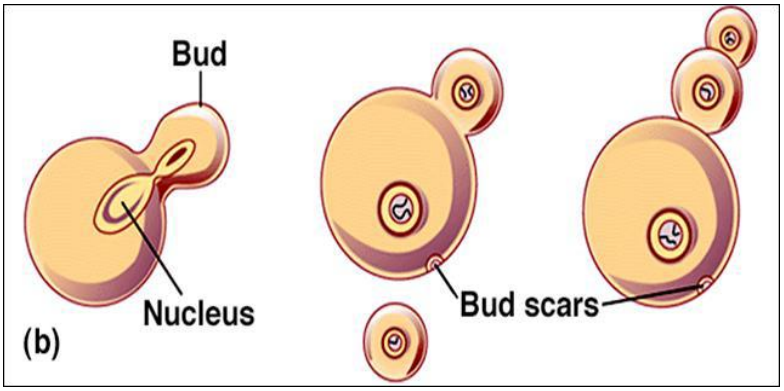
Arthrospores and chlamydospores

2) Simple fission of somatic cells into daughter cells

Fission, the simple splitting of a cell into two daughter cells by constriction and formation of a cell wall, is characteristic of a number of simple organisms including some yeast.

3) Budding of somatic cell or spores

Each bud producing a new individual. As the bud is formed, the nucleus of parent cell divides and one daughter nucleus migrates into the bud. The bud increases in size while still attached to the parent cell and eventually breaks off and form a new individual, example ***Saccharomyces* .**

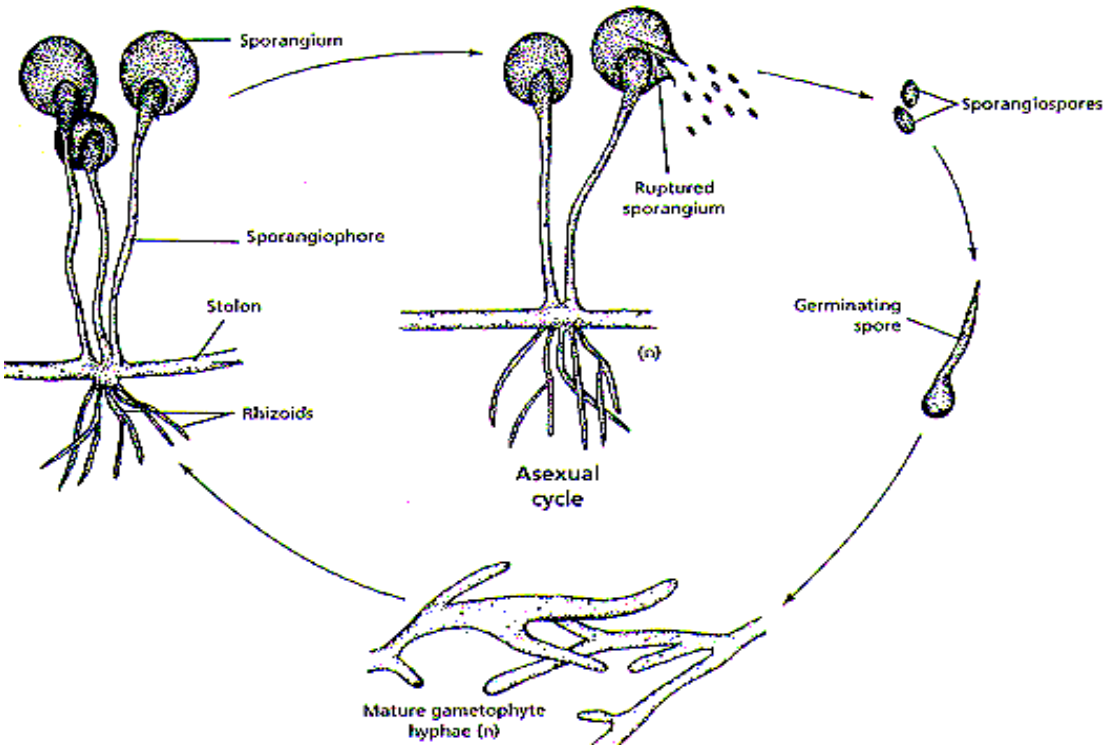


Budding

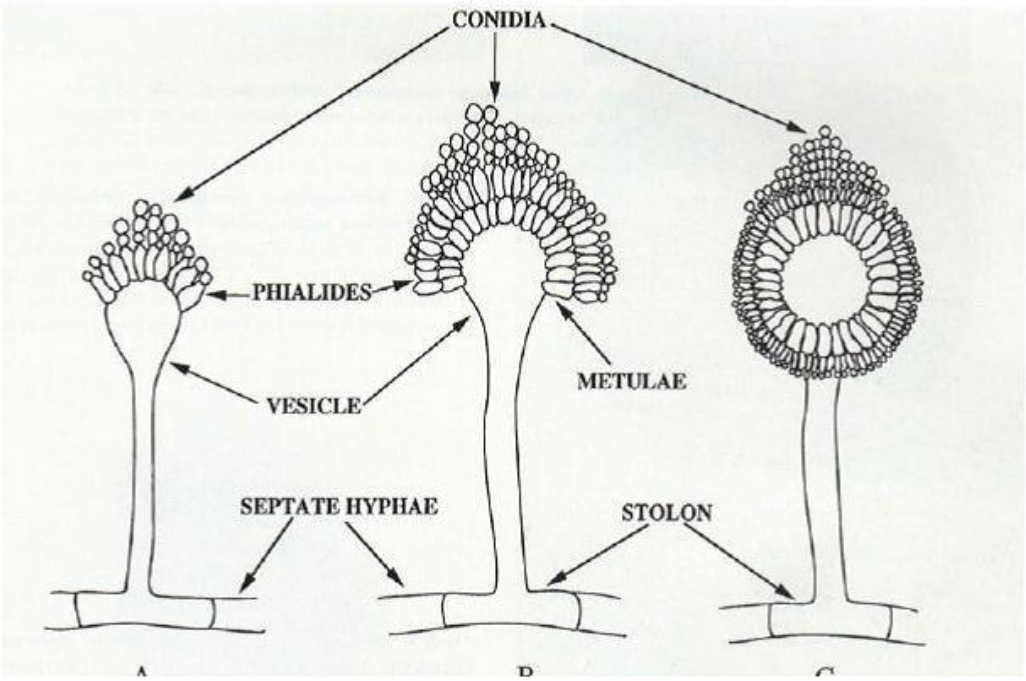
4) Spore formation(vegetative reproduction)

The most common method of asexual reproduction in fungi is by means of spores. Spores vary in color from hyaline through green, yellow, orange, red, brown to black; in size from minute to large; in shape from globose through oval, oblong, needle-shape to helical; in number of cell, from one to many; in the arrangement of cells; and in the way in which the spores them-self is borne . Some fungi produce only one type of spore, whereas other produces as many as four types. Fungal spores produced asexually are either borne in **sporangia** (sporangium) and then are called **Sporangiospores** as in ***Rhizopus*** and ***Mucor*** , or are produced at the tips or sides of hyphae in various ways and are then called **conidia** (conidium) as in ***Aspergillus* spp**.

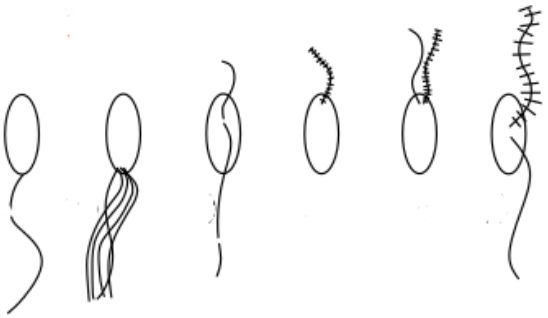
Sporangiospores may be motile or non- motile. In simpler fungi the Sporangiospores are usually motile and are called **zoospores**, if non- motile are called **aplanospores**. Fungal zoospores are equipped with one or two flagella (flagellum). There are at least two types of flagella in the fungi: The **whiplash** and **tinsel**. The flagella in fungi are differing in position, types, and number.



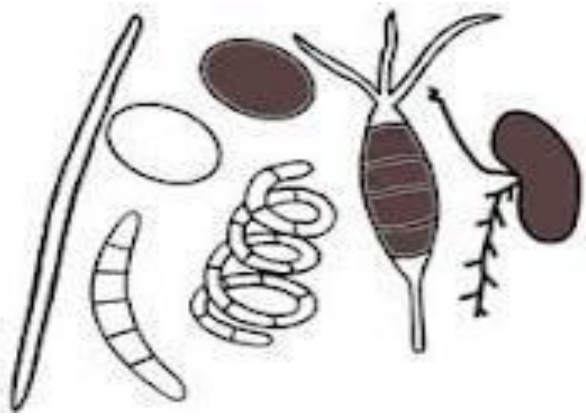
Sporangiospores formation in *Rhizopus*



conidia formation in *Aspergillus* spp.



Whiplash and tinsel flagella



Varity of spore shapes and size

Sexual reproduction

sexual reproduction in fungi as in other living organisms involves the union of two compatible nuclei. The process of sexual reproduction typically consist of three distinct phases:

1.Plasmogamy: a union of two protoplasts brings the nuclei close together within the same cell.

2.Karyogamy: The fusion of the two nuclei brought together by plasmogamy.

3.Mieosis: The reduction of chromosomes number to the half. Karyogamy follows plasmogamy almost immediately in many of the simpler fungi.

In the more complex fungi, however, those two processes are separated in time and space, with plasmogamy resulting in a binucleate cell containing one nucleus from each parent. Such pair of nuclei we call a **(Dikaryon)**. The sex organs of fungi are called **gametangia** (gametangium), these may form differentiated sex cell called **gametes** or may contain instead one or more gamete nuclei. We use the terms **(isogametangia and isogametes)** to designated gametangia and gametes that are morphologically indistinguishable; we use **(heterogametangia and heterogametes)** to designate male and female gametangium and gamete that are morphologically different, in the later case , the male gametangium is called the(**antheridium**) and the female is called the (**Oogonium**).

We now list the various methods by which compatible nuclei are brought together in the process of plasmogamy. These methods are often referred to as methods of sexual reproduction. Fungi employ five general methods to bring compatible nuclei together for fusion. These methods are:

1.Planogametic copulation: Planogametic copulation involves the fusion of two naked motile gametes (planogametes) as in ***Allomyces***.

2. Gametangial contact: Here gametes are not released from gametangia, instead male and female gametangia come in close contact with help of fertilization tube. Then one or more male nuclei migrate in to the female gametangium. The gametangia never fuse or lose their identity during the sexual act. Male gametangium is called antheridium and and female gametangium called Oogonium (Ascogonium in Ascomycota) Example: ***Albugo, Aspergillus, Pythium***

3.Gametangial copulation: he entire content of two compatible gametangia fuse each other The gametangia come in close contact, wall at the point of contact dissolves and their contents mix each other Then karyogamy is established .Example **zygomycota**

4.Spermatization: In some higher fungi sex organs are completely absent Here sexual process is accomplished by minute spore like spermatia and specialized (receptive) hyphae acting as male

and female structures respectively spermatia are carried by air, water or insect to the receptive hyphae. Spermatia attached to the trichogyne of receptive hyphae and migrate in to the cytoplasm .

5.Somatogamy. in this method, sex organs are not formed and two vegetative cells or vegetative hyphae take over the sexual function and fuse together
advanced fungal groups such as ***Morchella, Peziza, Agaricus***.

Sexual compatibility : Those in which every thallus is sexually self-fertile and, can therefore, reproduce sexually by itself without the aid of anther thallus, these type of fungi we called **(Homothallic fungi).** Those in which every thallus is sexually self-sterile, and requires the aid of anther compatible thallus or a different mating type for sexual reproduction, these types of fungi called **(Heterothallic fungi).**

Lecture 5: Taxonomy of Fungi

Taxonomy is the science of classification, i.e. the assigning of objects to defined categories. Classification has three main functions: it provides a framework of recognizable features by which an organism under examination can be identified; it is an attempt to group together organisms that are related to each other; and it assists in the retrieval of information about the identified organism in the form of a list or catalogue.

Traditional and modern taxonomic methods

Early philosophers classified matter into three Kingdoms: Animal, Vegetable, and Mineral. Fungi were placed in the Vegetable Kingdom because of certain similarities to plants such as their lack of mobility, absorptive nutrition, and reproduction by spores. Early systems of classification were based on morphological (macroscopic) similarity. But the invention of the light microscope revealed that structures such as fruit bodies which looked alike could be anatomically distinct and reproduce in fundamentally different ways, leading them to be classified apart.

Until the 1980s, the taxonomy of fungi was based mainly on light microscopic examination of typical morphological features, giving rise to classification schemes which are now known to be unnatural. Useful ultra-structural details, provided by transmission electron microscopy TEM, concern the appearance of mitochondria, properties of the septal pore, and details of the cell wall during spore formation or germination, or the arrangement of secretory vesicles in the apex of growing hyphae**.**

Biochemical methods have also made valuable contributions, especially in characterizing higher taxonomic levels. Examples include the chemical composition of the cell wall, alternative pathways of lysine biosynthesis, the occurrence of pigments and the types and amounts of sugars or polyols. Microscopic features are still important today for recognizing fungi and making an initial identification which can then, if necessary, be backed up

by molecular methods. Indeed, the comparison of DNA sequences obtained from fungi is meaningful only if these fungi have previously been characterized and named by conventional methods. It is therefore just as necessary today as it ever was to teach mycology students the art of examining and identifying fungi.

Fungi are a specific and large kingdom and it is difficult to classify them. So we must collect a lot of information starting with cultural characters reaching to the spore. Generally, the characters used in fungal classification are:

1. Cell wall
   Cell wall present: true fungi
   Cell wall absent: slime molds
2. Chemical components of cell wall
3. Somatic phase
4. Reproduction
5. Structure formed by fungi
6. Spores: size, color, shape, number of cell and type of spores.

Process of Classification

Have three distinct steps:

1. Identification
2. The relationships among other fungi and living organisms
3. Nomenclature

The mycologists of fungal taxonomy:

1. **Carl Linnaeus (1707-1778) the "Father of Taxonomy"**

" *Minerals exist; plants exist and live; animals exist, live and sense*."

Plants without obvious sexual organs were classified in Class Cryptogamia (lichens, **fungi**, mosses, ferns), fungi are primitive plants under this classification of organisms.

2. **R. H. Whittaker's 1969 Classification:** divided the living organisms in to five kingdoms according to cellular characterizations and he placed all eukaryotes, heterotrophs and have cell wall organisms in kingdom fungi **(see lecture 1).**
3. **Alexopoulos *et al*. : in his book "Introductory Mycology" 1962 ,2nd ed.**

   He put the fungi in one division "myota" and divided it into two subdivision as follow :

   1. Organisms of uncertain affinity Slime molds :
      Order: Acrasiales
      Order: Labyrinthulales
      ] some of slime molds
   2. Division: Mycota

   A. Sub division: Myxomycotina (slime molds)

   B. Eumycotina (true fungi)

      Classes: Chytridiomycetes, Hyphochytridiomycetes, Oomycetes, Plasmodiophoramycetes. Zygomycetes, Trichomycetes, Ascomycetes, Basidiomycetes and Deutromycetes.
4. **Alexopoulos *et al*. : in his book "Introductory Mycology" 1979 , 3rd ed.**

   He put the fungi in kingdom "Mycetae" and divided them in to three divisions as follow:

Kingdom: Mycetae
Division1: Gymnomycota
Division2: Mastigomycota
Division3: Amastigomycota

The classification system in fungi at this edition started with kingdom and end with species as follows:

Kingdom: Mycetae (Fungi)
Division: Mycota
Subdivision: Mycotina
Class: Mycetes
Subclass: Mycetidae
Series: Mycetes
Order: ales
Family: aceae
Genus and Species: There is no special ends

5. **Alexopoulos *et al*.: in his book "Introductory Mycology" 1996, 4th ed.**

   He put the fungi in three kingdoms and divided them in to phylum as follows:

   Kingdom1: protista

   Kingdom2: straminipila

   Kingdom3: true fungi

6. **Kendrick in his book " fifth kingdom"(2002) put the fungi in three groups**

   as follows:

   1: Pseudo Fungi: Included Slime Molds

   2:Simple Fungi

   3:True Fungi

7. **Minnesote University classification in USA(2005): divided fungi in**

   To two large super kingdoms as follows:

   1. **Super kingdom Eumycota :** included

      kingdom Eumycota

(Phylum : Chytridiomycota, Zygomycota, Ascomycota, Basidiomycota and form group Deurtomycota).

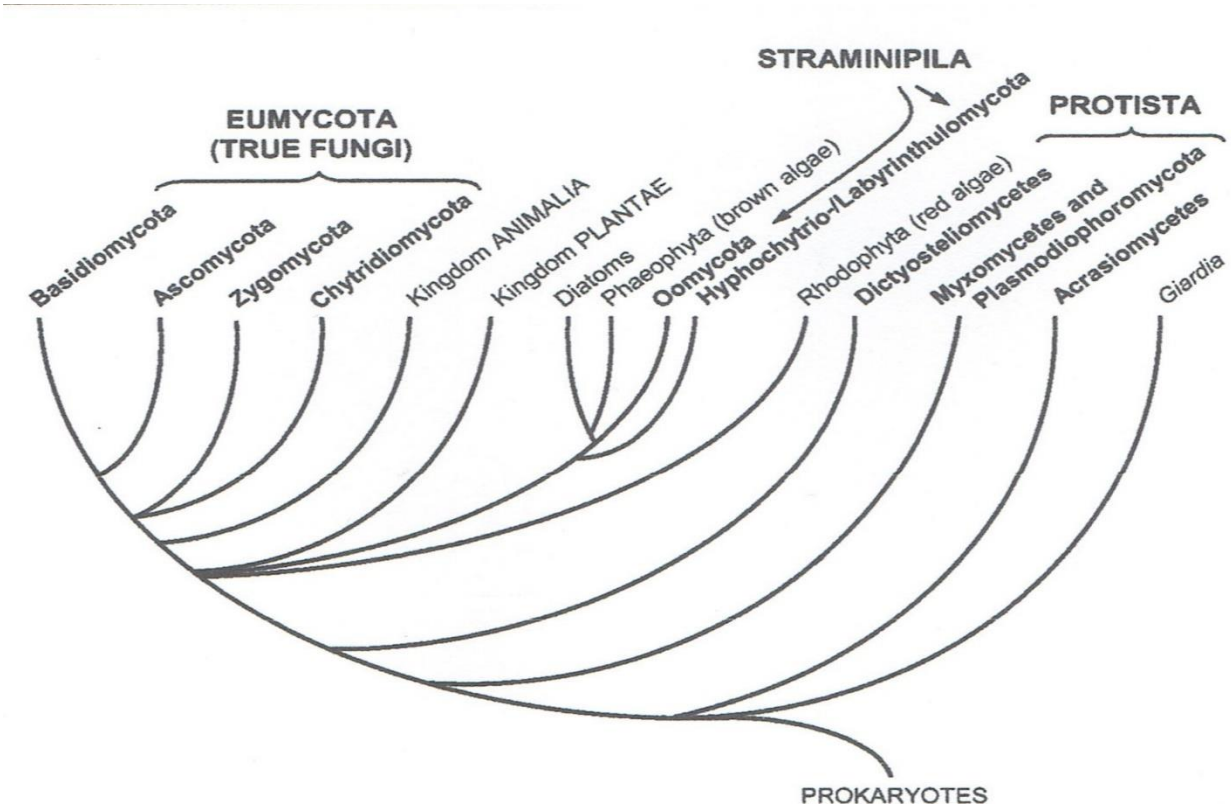
2. **Super kingdom Pseudomycota:** included
   a. kingdom Mycetozon **(** phylum: Myxomycota)
   b. kingdom protozoa **(**phylum: Plasmodiophoromycota)
   c. kingdom Straminipila or Chromista
   (Phylum: Oomycota and phylum: Hyphochytriomycota)

8. The modern classification:

At least 7 kingdoms are now recognized:

Eubacteria, Archaebacteria, Animalia, Plantae, Eumycota, Stramenopila (Chromista), Protoctista (Protozoa, Protista).

True fungi are recognized as kingdom: Fungi . While slime molds and lower fungi were distributed on two kingdoms: Chromista (Straminipila) and Protozoa.



The phylogenetic relationships of Fungi and fungus-like organisms studied by mycologists (printed in bold), with other groups of Eukaryota. The analysis is based on comparisons of18S rDNA sequences. Modified and redrawn from Bruns *et al.* (1991) and Berbee and Taylor (1999)

The classification scheme adopted in book of Webster and Weber (Introduction to Fungi, 2007 3rd ed.) , showing mainly those groups treated in some detail.

Kingdom1: Protozoa
Phylum1: Myxomycota
Phylum2: Plasmodiophoromycota

Kingdom2: Straminipila
(Minor fungal phyla)
Phylum1: Hyphochytriomycota
Phylum2: Labyrinthulomycota
Phylum3: Oomycota

Kingdom3: Fungi (Eumycota)
Phylum1 : Chytridiomycota
Phylum2 : Zygomycota
Phylum3 : Basidiomycota
Phylum 4: Ascomycota
Phylum 5: Anamorphic fungi