Principales of fungi

Course of Special Microbiology and

Microbiology-Chemistry Program

Course code: Mic202

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2022/2023

Content

Introduction to Fungi

Mycology: is the branch of science dealing with study of fungi "Greek, Mykes = mushrooms or fungus + Logos = subject. The term fungus (PL. Fungi) which originally means mushroom, but it is now applied to all types of fungi"

According to Alexopolus (1952), the fungus is defined as a nucleated achlorophyllous, thallophytes and usually filamentous, branched organisms which typically reproduce sexually and asexually and varies from bacteria by these previous features and the presence of cell wall surrounding the somatic cells split them from animal kingdom.

General Characteristics of True Fungi (Mycota or Eumycota)

1. All are eukaryotic: Possess membrane-bound nuclei (containing chromosomes) and a range of membrane-bound cytoplasmic organelles (e.g. mitochondria, vacuoles, endoplasmic reticulum).
2. Most are filamentous: Composed of individual microscopic filaments called hyphae, which exhibit apical growth and which branch to form a network of hyphae called a mycelium.
3. Some are unicellular e.g. yeasts.
4. Protoplasm of a hypha or cell is surrounded by a rigid wall composed primarily of chitin and glucans, although the walls of some species contain cellulose.
5. Many reproduce both sexually and asexually, both sexual and asexual reproduction often results in the production of spores.

6. Their nuclei are typically haploid and hyphal compartments are often multinucleate although the Oomycota and some yeast possess diploid nuclei.
7. All are achlorophyllous; they lack chlorophyll pigments and are incapable of photosynthesis.
8. All are chemoheterotrophic (chemo-organotrophic), they utilise pre-existing organic sources of carbon in their environment and the energy from chemical reactions to synthesise the organic compounds they require for growth and energy.
9. Possess characteristic range of storage compounds e.g. trehalose, glycogen, sugar alcohols and lipids.
10. May be free-living or may form intimate relationships with other organisms i.e. may be free-living, parasitic or mutualistic (symbiotic).

Occurrence

- They are universal in their distribution. In fact, they found in almost every available substrate on earth (tropical, subtropical, Arctic "cold regions" and ....etc) where the organic material (living or dead) is present.
- Many fungi grow in our foodstuffs such as bread, Jams, fruits ...etc. Also, they are present in all the times in the air surrounded us.
- Most of them are terrestrial occur in the soil; produce non-motile cells "advanced forms" which mainly dispersed by wind, water, or animals.... etc.
- Some others are aquatic (primitive forms) they produce motile cell which live on the decaying organic matter and living organism found in water.

Fungal Nutrition

- All fungi are chemoheterotrophic (chemo-organotrophic) synthesising the organic compounds they need for growth and energy from pre-existing organic sources in their environment, using the energy from chemical reactions.
- Since their protoplasm is protected by a rigid wall, fungi must obtain their nutrients by the process of Absorption.
- Small molecules (e.g. simple sugars, amino acids) in solution can be absorbed directly across the fungal wall and plasma membrane.
- Larger, more complex molecules (e.g. polymers such as polysaccharides and proteins) must be first broken down into smaller molecules, which can then be absorbed. This degradation takes place outside the fungal cell or hypha and is achieved by enzymes which are either released through or are bound to the fungal wall. Because these enzymes act outside the cell they are called extracellular enzymes.
- Since water is essential for the diffusion of extracellular enzymes and nutrients across the fungal wall and plasma membrane, actively growing fungi are usually restricted to relatively moist (or humid) environments.

Obligate Saprophytes

They are colonizing dead organic material, and these are saprobes or saprophytes. However, most of fungi can exist on dead organic material. Fungi which live only on dead organic material and unable to attack living organisms are obligate saprobes such as *Rhizopus*, *Penicillium* and *Aspergillus* species.

Facultative saprophytes

Those which can live parasitically according to the prevailing conditions are known as facultative saprobes as *Rhizoctonia* and *Pythium* species if not found suitable host, they live as saprobes.

Obligate parasites

They are those fungi which pass their entire life on living organisms e.g. rust fungi, powdery mildews and downy mildews.

Facultative parasites

Those which can live saprobically according to the prevailing conditions are known as facultative parasites such as *Fusarium* species. In other meaning, this group of fungi when found suitable host turned to parasite form.

Symbiosis (Mutalisms)

There is another type of association in which the fungus enters in a partnership with another organism. The best examples of symbioses are mycorrhizae (myco = fungus and rhiza = root) and lichens.

There are two types of mycorrhizae

Ectotrophic- Mycorrhizae

In which are mainly live on the outer root surface for example Ascomycota and Basidiomycota with the forest trees root system eg: - Gymnosperms and Angiosperms.

Endotrophic- Endomycorrhzae

In which the fungal cells penetrate the roots and grow in their tissues, it is mainly belonging to the root system of herbaceous plants and some primitive fungi as Glomeromycetes

Lichens

They consist of a fungal cell almost (85%) related to sac fungi (Ascolichens) and rarely to basidiomycota (Basidiolichens) and an algal cell mainly belonged to green algae (chlorophyta) and sometimes to blue green algae (cyanobacteria).

The body is termed as the thallus, and its shapes differentiated to mainly three groups: Foliose, Fruticose and crustose.

Environmental conditions for fungal growth

In common with all microorganisms, fungi are profoundly affected by physical and physicochemical factors, such as temperature, aeration, pH, water potential, and light. These factors not only affect the growth rate of fungi but also can act as triggers in developmental pathways. In this chapter we consider the effects of environmental factors on fungal growth, including the extremes of adaptation to environmental conditions which are:

- **temperature and fungal growth**
- **pH and fungal growth**
- **oxygen and fungal growth**
- **water availability and fungal growth**
- **effects of light on fungal growth**

Temperature: Microorganisms are often grouped into four broad categories in terms of their temperature ranges for growth: **psychrophiles** (cold-loving), **mesophiles** (which grow at moderate temperatures), **thermophiles** (heat-loving).

Fungi can be grouped into broad categories, according to their temperature ranges for growth as follows:

1- Psychrophiles "cold-loving":

They can grow at 0 °C, and some even as low as -10 °C, and their upper limit is often about 25 °C.

2- Mesophiles "room temperature":

They grow in moderate temperature range, minimum from about 10-20 °C, optimum 25-30 °C and maximum at 35 °C.

3- Thermophiles "heat-loving":

With an optimum growth temperature of 50 °C or more, a maximum of up to 70 °C or more, and minimum of about 40 °C.

4- Thermotolerants:

With optimum growth temperature of about 25 °C a maximum of up to 50 °C, and minimum of about 20 °C.

pH value

Fungi generally require an acidic medium for normal growth, with a pH of approximately 6.0. The optimum pH for growth of most of the fungi is 5.0 – 6.5; a few fungi grow much below pH 3.0 and a few others even above pH 9.0.

Several fungi are **acid-tolerant**, including some yeasts which grow in the stomachs of animals and some mycelial fungi (*Aspergillus*, *Penicillium*, and *Fusarium* spp.) which will grow at pH 2.0. But their pH optimum in culture is usually 5.5–6.0. Truly **acidophilic fungi**, able to grow down to pH 1 or 2, are found in a few environments such as coal refuse tips and acidic mine wastes; many of these species are yeasts

Light

Most fungi do not require light for their vegetative growth. However, it is needed by many species for sporulation and spore dispersal. Light in the near-ultraviolet (NUV) and visible parts of the spectrum (from about 380 to 720 nm) has relatively little effect on vegetative growth of fungi, although it can stimulate pigmentation. In particular, blue light induces the production of carotenoid pigments in hyphae and spores of several fungi, including Neurospora crassa. These carotenoids, which also occur in algae and bacteria, are known to quench reactive oxygen species, The pigments serve to minimize photo induced damage. Melanins similarly protect cells against reactive oxygen species and ultraviolet radiation.

Oxygen supply

Most fungi are strict aerobes, in the sense that they require oxygen in at least some stages of their life cycle. It is also an important factor for fungal growth. Most of the fungi are aerobic and stop growing in the absence of oxygen. Even ***Saccharomyces cerevisiae***, which can grow continuously by fermenting sugars in anaerobic conditions, needs to be supplied with several preformed vitamins, sterols and fatty acids for growth in the absence of oxygen. Saccharomyces also requires oxygen for sexual reproduction.

1- Obligate aerobes

their growth is reduced if the partial pressure of oxygen is lowered much below that of air. For example, growth of the take-all fungus of cereals is reduced. Aerobic fungi typically use oxygen as their terminal electron acceptor in respiration. This gives the highest energy yield from the oxidation of organic compounds.

2- Facultative aerobes

Many yeasts and several mycelial fungi (e.g. *Fusarium oxysporum*, *Mucor hiemalis*, *Aspergillus fumigatus*) are **facultative aerobes**They grow in aerobic conditions but also can grow in the absence of oxygen by fermenting sugars. The energy yield from fermentation is much lower than from aerobic respiration, and the biomass production is often less than 10% of that in aerobic culture. However, a few mycelial fungi can use nitrate instead of oxygen as their terminal electron acceptor. This anaerobic respiration can give an energy yield at least 50% of that from aerobic respiration.

3- obligate fermentative

A few aquatic fungi are **obligately fermentative**, because they lack mitochondria or cytochromes (e.g. ***Oomycota***) or they have rudimentary mitochondria and low cytochrome content (e.g. *Blastocladiella ramosa*, *Chytridiomycota*). They grow in the presence or absence of oxygen, but their energy always comes from fermentation

Water

Like other living organisms, water is an essential requirement for all fungi. Without water, fungi are unable to grow or reproduce. All fungi need the physical presence of water for uptake of nutrients through the wall and cell membrane, and often for the release of extracellular enzymes. Fungi also need intracellular water as a milieu for metabolic reactions. However, water can be present in an environment and still be unavailable because it is bound by external forces. Whether water enters or leaves a cell depends on the difference between the water potential of the cell and that of the surrounding medium, water moving from a region of high to one of lower water potential.

Of all the factors that have been studied which affect fungal growth, water has been proven to be a major determinant, along with temperature and time .As a result, flooded areas tend to experience significant fungal exposure. The Centre for Disease Control noted that mould growth will develop on materials that remain wet for 48-72 hours. Fungi that grow on particular material are known as ‘associated’ fungi and categorized into three groups based on their water activity aw (aw x 100=% relative humidity at equilibrium). These categories consist of: i) **primary colonizers** that are storage moulds which grow at aw of less than 0.8 (low moisture level in material), such as *Aspergillus versicolor* (at 12^0 C), and less frequently *A. fumigatus*, *A. niger*, *Penicillium palitans*, *Paecilomyces variotii*, ii) **secondary colonizers** that require a minimum aw of 0.8-0.9 (intermediate moisture level) including *Alternaria*, *Cladosporium*, *Phoma*, *Ulocladium*, *A. fumigatus* and *A. versicolor* (at 25^0 C); and iii) **tertiary colonizers** known as water damage moulds that require aw of at least 0.9 or higher (high moisture level), such as *Chaetomium globosum*, *Stachybotrys chartarum*, and *Trichoderma*

Ultrastructure and Function of Fungal Cells

1- The Fungal Cell Surface

The fungal cell wall is a dynamic structure that protects the cell from changes in osmotic pressure and other environmental stresses, while allowing the fungal cell to interact with its environment. The structure and biosynthesis of a fungal cell wall is unique to the fungi, and is therefore an excellent target for the development of antifungal drugs.

In filamentous fungi, cell-wall formation and organization is intimately bound to the process of apical growth. Thus, for example in *Neurospora crassa*, the wall is thin (approximately 50 nm) at the apex but becomes thicker (approximately 125 nm) at 250 μm behind the tip. The plasma membrane component of the fungal cell envelope is a phospholipid bilayer interspersed with globular proteins that dictates entry of nutrients and exit of metabolites and represents a selective barrier for their translocation

Ergosterol is the major sterol found in the membranes of fungi, in contrast to the cholesterol found in the membranes of animals and phytosterols in plants. This distinction is exploited during the use of certain antifungal agents used to treat some fungal infections, and can be used as an assay tool to quantify fungal growth. The periplasm, or periplasmic space, is the region external to the plasma membrane and internal to the cell wall.

In yeast cells, it comprises secreted proteins (mannoproteins) and enzymes (such as invertase and acid phosphatase) that are unable to traverse the cell wall. In filamentous fungi, the cell membrane and wall may be intimately bound as hyphae and are often resistant to plasmolysis.

Ultrastructural analysis of fungal cell walls reveals a thick, complex fibrillar network. The cell walls of filamentous fungi are mainly composed of different polysaccharides according to taxonomic group. For example, they may contain either chitin, glucans, mannoproteins, chitosan, polyglucuronic acid or cellulose, together with smaller quantities of proteins and glycoproteins.

In yeasts, the cell-wall structure comprises polysaccharides (predominantly β-glucans for rigidity), proteins (mainly mannoproteins on the outermost layer for determining porosity), together with some lipid, chitin (e.g. in bud scar tissue) and inorganic phosphate material. Hyphal cell walls generally contain fewer mannans than yeast cell forms, and such changes in composition are even observed during the transition from unicellular to mycelial growth of dimorphic fungi.

Chitin is also found in yeast cell walls and is a major constituent of bud scars. These are remnants of previous budding events found on the surface of mother cells following birth of daughter cells (buds). The chitin-rich bud scars of yeast cells can be stained with fluorescent dyes (e.g. calcoflour white), and this can provide useful information regarding cellular age, since the number of scars represents the number of completed cell division cycles.

2- Membrane bound organelles

The following membrane-bound organelles may be found in a typical fungal cell: nucleus: endoplasmic reticulum (ER), mitochondria, Golgi apparatus, secretory vesicles and vacuoles. Several of these organelles form extended membranous systems. For example, the ER is contiguous with the nuclear membrane and secretion of fungal proteins involves inter membrane trafficking in which the ER, Golgi apparatus, plasma membrane and vesicles all participate. The physiological function of the various fungal cell organelles is summarized in this table (1):

Table (1): Functional components of an idealized fungal cell.

Organelle or cellular structure	Function
Cell envelope	Comprising: the plasma membrane, which acts as a selectively permeable barrier for transport of hydrophilic molecules in and out of fungal cells; the periplasm, containing proteins and enzymes unable to permeate the cell wall; the cell wall, which provides protection, shape and is involved in cell–cell interactions, signal reception and specialized enzyme activities; fimbriae involved in sexual conjugation; capsules to protect cells from dehydration and immunecell attack.

Nucleus	Relatively small. Containing chromosomes (DNA–protein complexes) that pass genetic information to daughter cells at cell division and the nucleolus, which is the site of ribosomal RNA transcription and processing
Mitochondria	Site of respiratory metabolism under aerobic conditions and, under anaerobic conditions, for fatty acid, sterol and amino acid metabolism.
Endoplasmic reticulum	Ribosomes on the rough ER are the sites of protein biosynthesis.
Proteasome	Multi-subunit protease complexes involved in regulating protein turnover.
Golgi apparatus and vesicles	Secretory system for import (endocytosis) and export (exocytosis) of proteins.
Vacuole	Intracellular reservoir (amino acids, polyphosphate, metal ions); proteolysis; protein trafficking; control of cellular pH. In filamentous fungi, tubular vacuoles transport materials bidirectionally along hyphae.
Peroxisome	Oxidative utilization of specific carbon and nitrogen sources (contain catalase, oxidases). Glyoxysomes contain enzymes of the glyoxylate cycle

The Cell Wall of the Fungal Cell:

The composition of cell wall is variable among the different groups of fungi or between the different species of the same group. In the majority of fungi, the wall lacks cellulose but contains a form of chitin known as the fungus cellulose which is strictly not identical with insect chitin. The basic structural constituent of the cell wall in the Zygomycetes and higher fungi (Ascomycetes and Basidiomycetes) is chitin. It is a polysaccharide based on the nitrogen containing sugar (glucosamine). It is probable that more or less closely associated with chitin in the cell wall are pectic materials, protein, lipids, cellulose, callose and minerals.

The clear evidence of such an association is, however, lacking. Burnet (1968) is of the opinion that insoluble B glucan forms the predominant structural material of the wall of Ascomycetes and Basi-diomycetes. In addition chitin may as well be present in appreciable amounts. In the yeasts and a few other Hemias- comycetideae chitin is absent. Their walls are mainly composed of micro-fibrils of mannan and B glucan. Mannan is a polymer of hexose sugar mannose whereas glucan is polymer of glucose. Some investigators have reported the occurrence of lignin in several fungi It is doubtful whether this substance is chemically the same as the lignin of higher plants.

Functions:

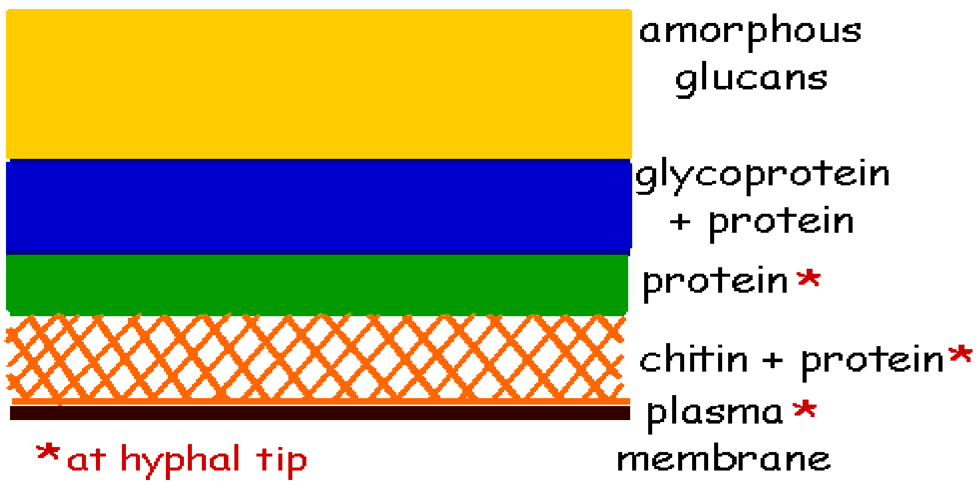
- Protect the underlying protoplasm.
- Determines and maintains the shape of the fungal cell or hypha; if you remove the wall the resulting protoplast will always assume a spherical shape.
- Acts as an interface between the fungus and its environment.
- Acts as a binding site for some enzymes.
- Possesses antigenic properties which allow interactions with other organisms.

Chemical composition of the wall:

- Polymeric fibrils
    - Chitin
    - Cellulose (in the Oomycota)
- Amorphous matrix components
    - Glucans

- Proteins
- Lipids
- Heteropolymers (mixed polymers) of mannose, galactose, fructose and xylose.

The types and amounts of these various components vary amongst different groups of fungi and may even vary during the life cycle of a single species.



The diagram above represents a section through the mature lateral wall of hyphae of *Neurospora crassa*.

- In general, the inner part of the wall consists of polymeric fibrils embedded in an amorphous matrix and this is covered by further layers of matrix material.
- At the hyphal tip the wall is thinner and simpler in structure, consisting of only two layers, the inner layer of fibrils embedded in protein and outer layer of mainly protein.
- Extra layers of wall material are deposited in the lateral walls behind the extending apex strengthening the wall as the hypha matures.

- In the oldest parts of the hyphae (and in many fungal spores) lipids and pigments may be deposited in the wall:
    - Lipids serve as a nutrient reserve and help prevent desiccation
    - Pigments, such as melanin, help protect the protoplast against the damaging effects of UV radiation.

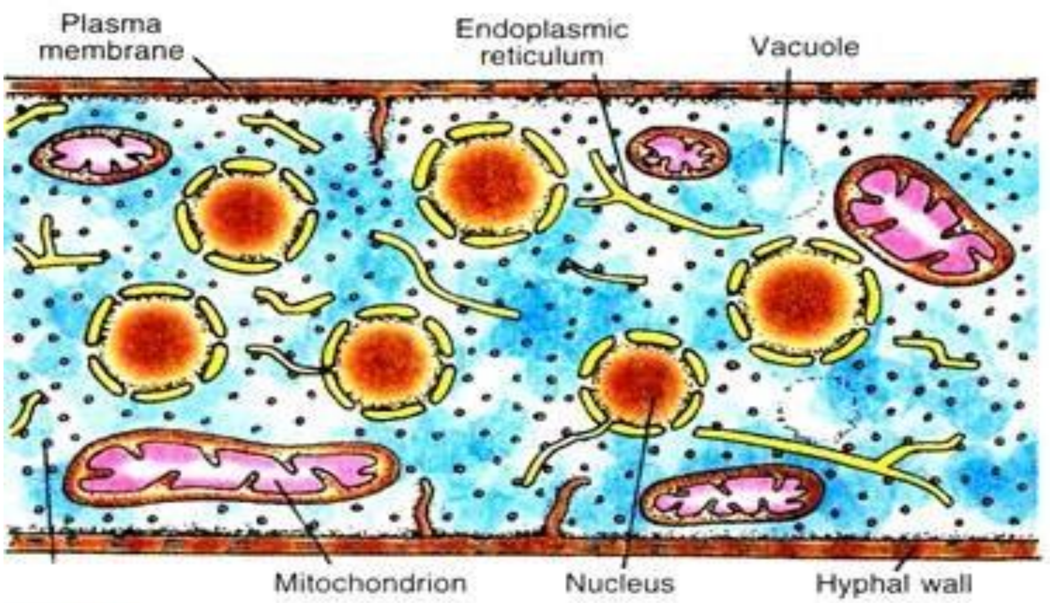


Fig. 1.9. *Fungi*. Fine structure of a hypha near the growing tip of *Mucor* based on an electron micrograph.

(b) The Protoplast in the Fungal Cell:

The living substance of the cell within the cell wall is the protoplast. It lacks the chloroplasts but is differentiated into the other usual cell parts such as plasma or cell membrane, vacuolated cytoplasm, cell organelles and one or more nuclei.

Cell Membrane(plasma membrane):

It is a delicate, extremely thin, living membrane which closely invests the protoplast. The cell or plasma membrane is pressed against the cell or hyphal wall except for occasional invaginations in some regions. A phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. The plasma membrane controls the passage of organic molecules, ions, water, and oxygen into and out of the cell. Wastes (such as carbon dioxide and ammonia) also leave the cell by passing through the plasma membrane, usually with some help of protein transporters.

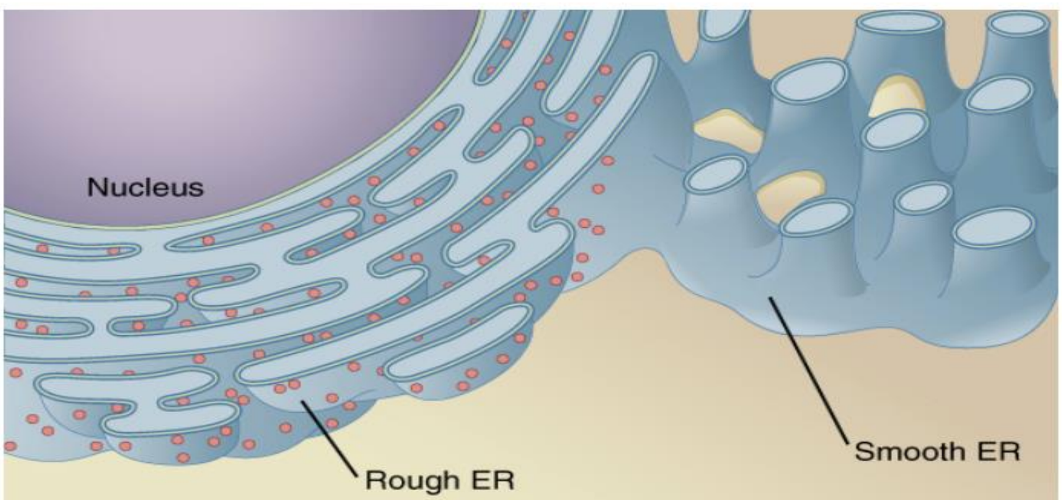
Cytoplasm:

Within the plasma membrane is the colorless cytoplasm in which sap-filled vacuoles may occur. In young hyphae and hyphal tips, the cytoplasm appears rather uniform and homogeneous. Immersed in the cytoplasm are structures known as the organelles and inclusions.The organelles are living structures, each with a specific function. The inclusions are dead, have no specific function and thus are not essential to cell survival.

Amongst the cell organelles are included the endoplasmic reticulum,mitochondria, ribosomes, Golgi apparatus and vacuoles. Lomasomes which are membranous structures lying between the cell wall and plasma membrane are common. Examples of inclusions are the stored foods (glycogen, and oil drops) pigments and secretory granules.

Endoplasmic Reticulum:

The presence of endoplasmic reticulum in the fungal cytoplasm has been demonstrated by the use of electron micro-scope. It is composed of a system of membranes or microtubular structures usually beset with small granules which by some scientists are likened to the ribosomes. In many fungi, the endoplasmic reticulum is highly vesicular. Usually it is loose and more irregular than in the cells of green plants. The endoplasmic reticulum is composed of a group of interconnected sac-like structures called tubules. These tubules collectively modify and produce the proteins and lipids. It is a complex and large structure in the cytoplasm and spans between the cell membrane and the nucleus. The endoplasmic reticulum is classified into two types, rough endoplasmic reticulum (Rough ER) and smooth endoplasmic reticulum (smooth ER). Rough endoplasmic reticulum is the site of protein synthesis. Smooth endoplasmic reticulum is the site of production of lipids.

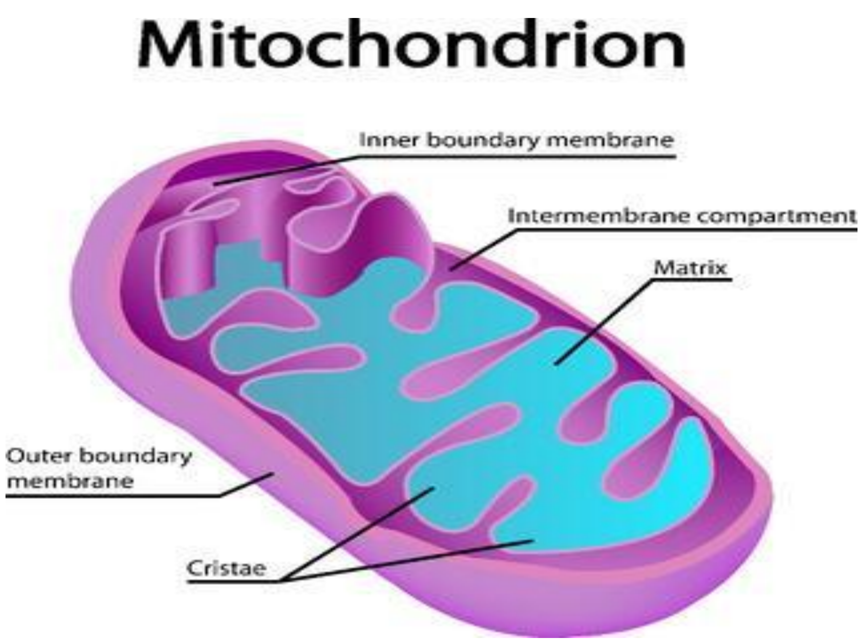


Mitochondria:

The cytoplasm contains small, usually spherical bodies known as the mitochondria. Each mitochondrion is enveloped by a double membrane.] A mitochondrion contains outer and inner membranes composed of phospholipid bilayers and proteins.The two membranes have different properties. Because of this double-membraned organization, there are five distinct parts to a mitochondrion:

1. The outer mitochondrial membrane,
2. The intermembrane space (the space between the outer and inner membranes),
3. The inner mitochondrial membrane,
4. The cristae space (formed by infoldings of the inner membrane), and
5. The matrix (space within the inner membrane), which is a fluid.

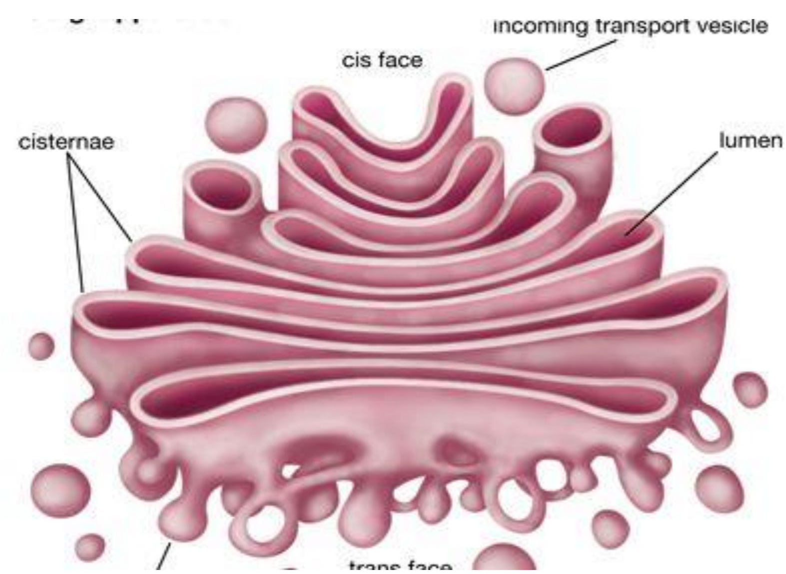
The inner membrane is infolded to form the cristae which are in the form of parallel flat plates or irregular tubules.The cristae contain the same fluid that fills the space between the two membranes. The mitochondria function as the power house of the cell. There is no fundamental difference between the mitochondria of fungi and those of green plants. However, Hawker (1965) holds that the cristae of fungal mitochondria are fewer, flatter and more irregular than those of the green plants.



Golgi Apparatus (Dictyosomes):

The Golgi apparatus is responsible for transporting, modifying, and packaging proteins and lipids into vesicles for delivery to targeted destinations. It is located in the cytoplasm next to the endoplasmic reticulum and near the cell nucleus. While many types of cells contain only one or several Golgi apparatus, plant cells can contain hundreds. Secretory proteins and glycoproteins, cell membrane proteins, lysosomal proteins, and some glycolipids all pass through the Golgi apparatus at some point in their maturation.

In general, the Golgi apparatus is made up of approximately four to eight cisternae, although in some single-celled organisms it may consist of as many as 60 cisternae. The cisternae are held together by matrix proteins, and the whole of the Golgi apparatus is supported by cytoplasmic microtubules. The three primary compartments of the apparatus are known generally as "cis" (cisternae nearest the endoplasmic reticulum), "medial" (central layers of cisternae), and "trans" (cisternae farthest from the endoplasmic reticulum). Moore and Muhlethaler (1963) reported a golgi apparatus consisting of three flattened sacs surrounded by many bubble-like structures in Saccharomyces cells.



Vacuole:

The cytoplasm of young hyphae or fungal cells and hyphal tips lacks vacuoles. They appear further back or in the old cells. With age, they enlarge and show a tendency to coalesce and ultimately reduce the cytoplasm to thin lining layer immediately within the cell wall. acuole is an important organelle. They store food and water as well as waste material before it is transported out of the cell. Vacuole's also provide turgor pressure against the cell. Plant’s vacuole Eukaryotic cell is surrounded with cell wall. The cell wall is the rigid, semi- permeable protective layer found in some cell types. The cell wall is an extracellular structure of cells that maintains cell's shape and protects cell from mechanical damage. Cytoplasmic inclusions are temporary structures that accumulate in the cytoplasm of certain cells . Examples: lipids, glycogen, crystals, pigment, or byproducts of metabolism are inclusions.

Nucleus:

The cytoplasm in the individual cells contains one, two or more globose or ellipsoid nuclei which in the somatic portion are small and usually range from 1-2 or 3μ in diameter. They cannot be seen without special techniques.

Structurally the nucleus consists of:

(i) A central, dense body with a clear area around it.

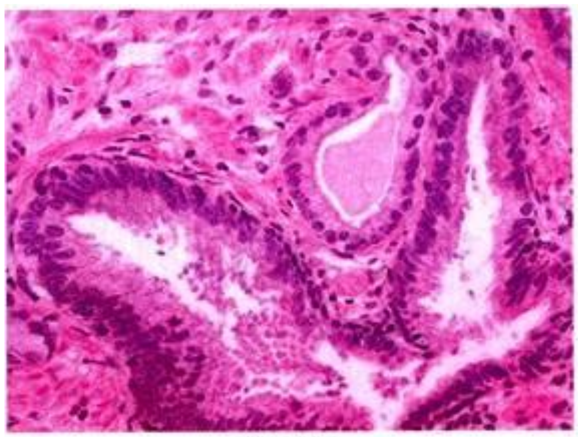
(ii) Chromatin strands

(iii) The whole structure surrounded by a definite nuclear, membrane.

The nucleus is the structure that defines the eukaryotic nature of fungal cells. It is bound by a double membrane and encases the chromosomes in a nucleoplasm. Most yeast and fungi are haploid, although some (e.g. *S. cerevisiae)* may alternate between haploidy and diploidy.

Yeasts usually contain a single nucleus per cell. However, the hyphal compartments of filamentous fungi may contain one or more nuclei. Monokaryotic basidiomycetes possess one nucleus per compartment, whereas dikaryons or heterokaryons possess two or more genetically distinct haploid nuclei.The maintenance of multiple nuclei within individual hyphal compartments allows fungi to take advantage of both haploid and diploid lifestyle.

In electron micrographs, it appears as an amorphous or granular mass. Mycologists usually designate it as the nucleolus. Bakerspigel (1960) stated that it contains RNA. During nuclear division, the chromatin strands become organised into chromosomes which are extremely small and difficult to count. Under the electron microscope, the nuclear membrane is seen to consist of inner and outer layers of electron dense material and the middle one of electron transparent substance. The nuclear membrane has pores. At certain points, the nuclear membrane is continuous with the endoplasmic reticulum.



Nucleolus.

Lysosome

Lysosome is responsible for the digestion of macromolecules, old cell parts, and microorganisms. Lysosomes contain a wide variety of hydrolytic enzymes (acid hydrolases) that break down macromolecules such as nucleic acids, proteins, and polysaccharides Additionally, eukaryotic cells have ribosomes (with diameter around 20 nm) which translate genetic information into proteins

Peroxisome

Like the lysosome, the peroxisome is a spherical organelle responsible for destroying its contents. Unlike the lysosome, which mostly degrades proteins, the peroxisome is the site of fatty acid breakdown. It also protects the cell from reactive oxygen species (ROS) molecules which could seriously damage the cell. ROSs are molecules like oxygen ions or peroxides that are created as a byproduct of normal cellular metabolism, but also by radiation, tobacco, and drugs. They cause what is known as oxidative stress in the cell by reacting with and damaging DNA and lipid-based molecules like cell membranes. These ROSs are the reason we need antioxidants in our diet.

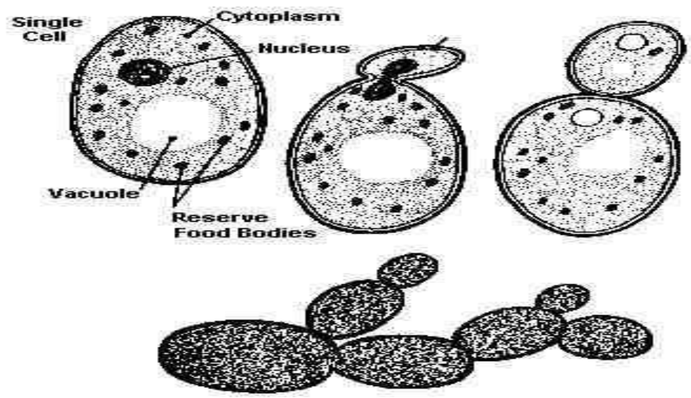
What Do Fungi Look Like?

Many of us are familiar with the appearance of mushrooms and toadstools. But these structures are simply the large, macroscopic fruiting bodies produced by some groups of fungi. The actively growing and reproductive structures of most species are microscopic, and although most fungi are mycelial (filamentous), there are some exceptions to this growth form.

- Unicellular form (Yeasts)
- Mycelial (filamentous)
- Unicellular and primitively branched Chytrids
- Dimorphism

Unicellular form (Yeasts)

For example the yeasts, it is consists of a single, minute, oval or spherical cell. The cell wall is mainly made up only from glucan and chitin. It contain nucleus and nucleolus and mitocondria, and the main reserve food products are glycogen, oil, volutin and protein bodies.



General characteristics of Yeast

- Yeast is basically chemorganotrophs as they can use the inorganic chemical as a source of energy.
- Mostly yeast isolated from the surfaces of fruit and berries like apple, peaches and exudates from plants such as plants saps or cacti.
- Yeast can be present in the gut flora of mammals and some insects and even in the deep-sea environment.
- Yeast mostly grows at a temperature ranging between 20 to 28 degree Celsius at an acidic pH of 3.5 to 4.
- For maintenance and preservation of yeast culture slant with 2%, caco3 can be used.
- Classification of yeast can be done using its morphological characteristics, cultural characteristics and sexual characteristics and physiological characteristics.

Morphological characteristics:-

- The characteristics of vegetative reproduction and a vegetative cell can be used to classify yeast.

-
- Vegetative reproduction is done either by fission or by budding or by the formation of conidia.
-
- Reproduction by fission is a typical characteristic of endomycetacea.

- Morphology of the vegetative cells cultivated in liquid and solid media is founded on whether the cells are spherical, ovoid, cylindrical etc.

Physiological characteristics:-

- Yeast developing on a carbon source must either be able to format it or utilise it by respiration.

- It has been found that when yeast utilises carbon source fermentatively it is also able to utilise it oxidatively.

- The ability or inability to ferment carbohydrates to ethanol and carbon dioxide is the most important for differentiating spaces.

- Variety of sugars is formatted by a variety of yeast.
- Nitrogen metabolism is the fundamental feature of development the ability or inability to utilise various derivations of nitrogen can be made use of in classifying yeast.

- The use of the ability or inability to grow in a synthetic medium devoid of vitamins like biotin and folic acid, inositol etc.

- Except for genus saccharomyces which only grows in media containing certain east or protein hydrolysates all yeast can utilise a variety of nitrogen sources.

- Practically every yeast uses urea at low concentration as a single source of nitrogen contributed that a sufficient amount of vitamins are supplied.

- Fermentative yeast from a variety of oysters is varying amounts.

- Ethyl acetate has been found to be the commonest and the most readily detectable Easter formed by yeast.

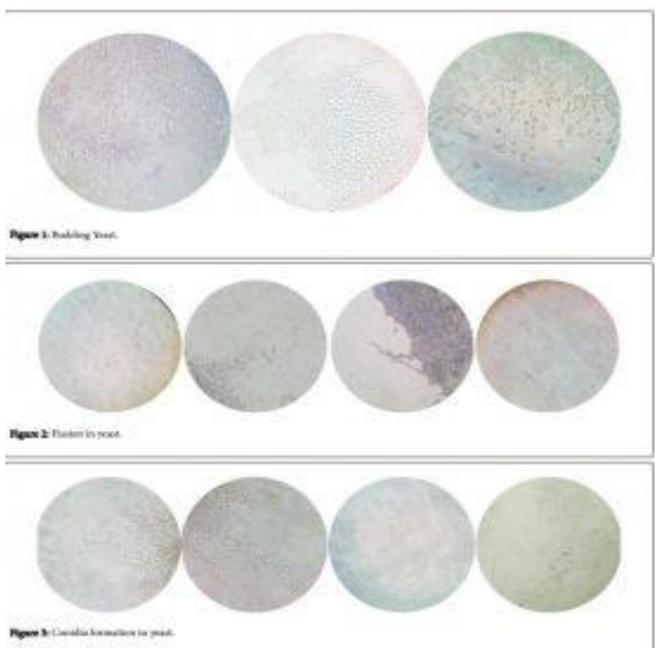
- It is approved that the potential of yeast to soften gelatin is a very restricted taxonomic importance as very few are strongly proteolytic.

Cultural characteristics:-

- Yeast grown in watery media may result in the formation of residue a ring, a pellicle.

- Pellicle formation on a watery medium is a product associated with oxygen demand of yeast.

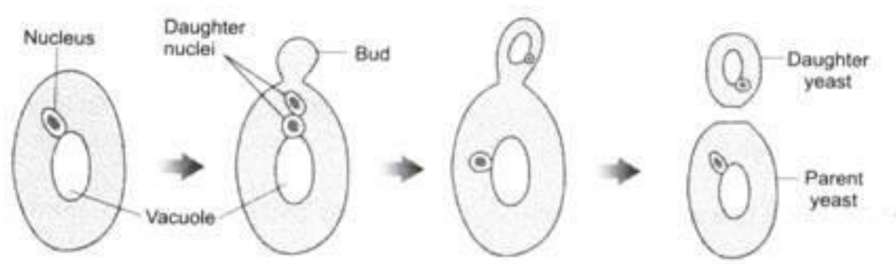
- Growth on solid media may be either butyrous, friable, pigmented.
- Lipomyces shows characteristics of mucoid growth.



Asexual Reproduction

Budding: Most of the yeasts multiply asexually by vegetative method called budding, under favourable conditions Saccharomyces reproduce by this method. At the time of budding, a small portion of the cell wall at or near one pole of the yeast cell softens and thin. The protoplast in this region, bulges out in the form of an outgrowth (protuberance), covered by the thin softened membrane. Outgrowth gradually increases in size and known as the bud. As the bud is forming, the nucleus of parent yeast cell divides forming two nuclei. The daughter nuclei migrate into enlarging bud. The bud grows, and the cytoplasm of the bud and mother cell remains continuous for sometimes. Eventually the opening between the two cells closes, and then the bud separates from mother cell leaving a scar on both cells. In the presence of abundant food supply, the process of budding is quickened. It becomes so rapid that the buds often produce buds before separation from the mother cell, the process is repeated, in this way many buds are formed without being detached from one another, this result in the formation of branched or unbranched chains of cells constituting the pseudomycelium.

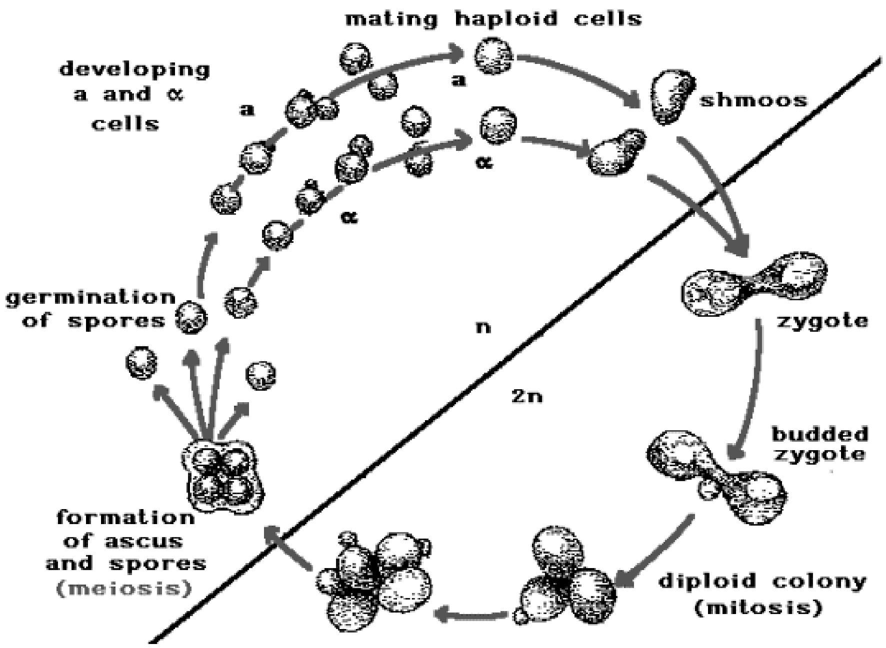
Fission: Vegetative reproduction by fission has also been reported but it occurs in some other yeast and not in Saccharomyces. They are called fission yeasts for this reason. The division is transverse. The mother cell elongates, and the nucleus divides into two. Meanwhile a ring-like ingrowth appears at the wall of the yeast cell in the middle, it grows in ward toward the centre of the cell. Finally, it stretches across the cell forming a complete partition called septum. The septum thickens and then splits into two layers, one for each daughter cell.



Budding in yeast

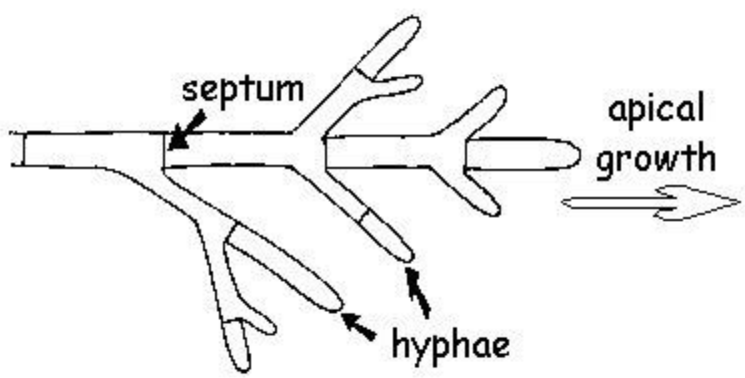
Sexual reproduction

Sexual reproductions started by two haploid cells of the opposite mating types bends towards each other and fuse to form Conjugation Bridge. Fusion between the protoplast of the (+) and (–) strains takes place through the conjugation bridge called plasmogamy. Then karyogamy occurs by fusion of two nuclei forming diploid nucleus (2N) called zygote. The zygote become spherical in shape and directly functions as ascus mother cell. Then the diploid nucleus of ascus mother cell undergoes meiosis forming four haploid nuclei which surrounded by cytoplasm to produce ascospores. Ascospores liberate from the ascus mother cell and germinate forming new yeast cell.



Life cycle of *Saccharomyces*

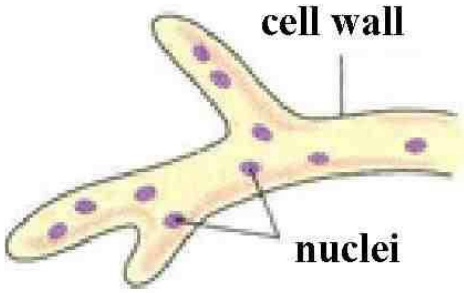
Mycelial (filamentous)



Most fungi are composed of microscopic filaments called hyphae, which branch to eventually form a network of hyphae, called a mycelium (colony). The mycelium extends over or through what ever substrate the fungus is using as a source of food. Each hypha is essentially a tube, containing protoplasm surrounded by a rigid wall composed from chitin.

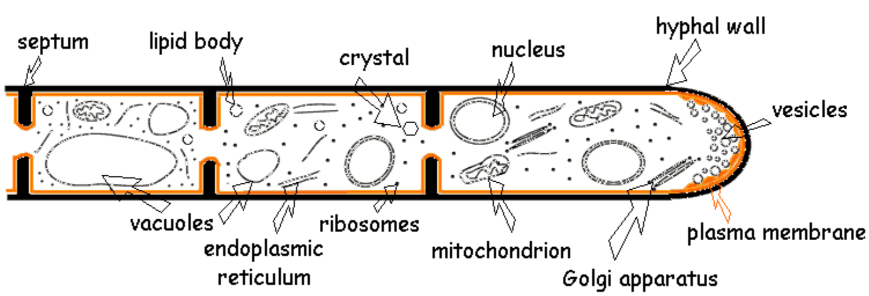
1- Aseptate hyphae

In this case, protoplasm may form a continuous, uninterrupted mass running the length of the branching hyphae, in the other word, the nuclei are embedded in the cytoplasm and arranged regularly along the whole mass of the cytoplasm. The hyphae in this case is coenocyte

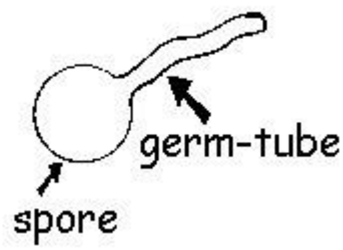


2- Septate hyphae

In this case the protoplasm may be interrupted at intervals by cross-walls called septa. Septa divide up hyphae into individual discrete cells or interconnected hyphal compartments.

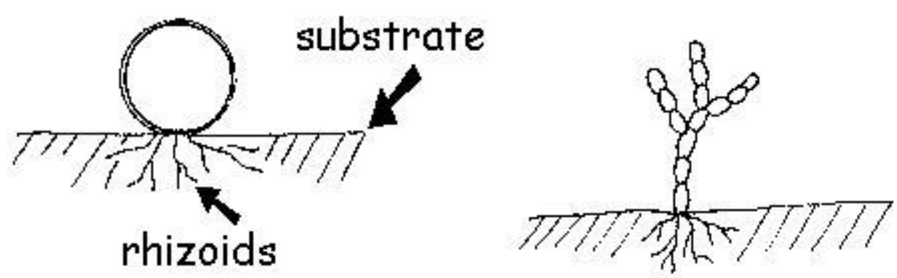


Hyphae exhibit apical growth (i.e. they elongate at their tips) and, at least in theory, can grow indefinitely , provided that environmental conditions remain favourable for growth. Of course, their environment eventually limits or restricts their growth.



Hyphae may initially develop from a germ-tube (a short, immature hypha) that emerges from a germinating spore. Spores are the microscopic dispersal or survival propagules produced by many species of fungi.

3- Unicellular and primitively branched Chytrids (Chytridiomycota)



Fungi belonging to the Chytridiomycota exist as either single round cells (unicellular species) or primitively branched chains of cells. In either case, the fungus may be anchored to its substrate by structures called rhizoids.

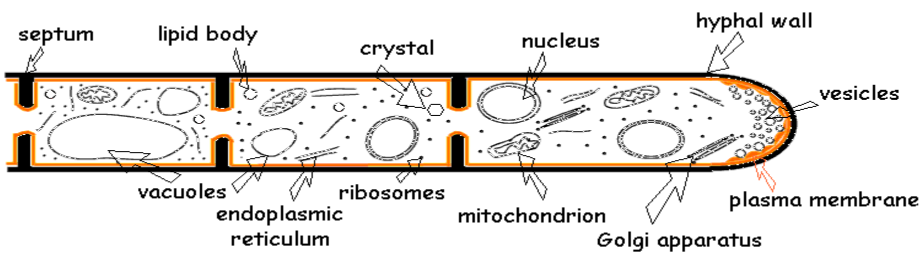
- Like protists, chytrids usually live in aquatic environments, but some species live on land.
- Some chytrids are saprobes while others are parasites that may be harmful to amphibians and other animals.
- Chytrids reproduce both sexually and asexually, which leads to the production of zoospores.
- Chytrids have chitin in their cell walls; one unique group also has cellulose along with chitin.
- Most chytrids are unicellular; a few form multicellular organisms and hyphae, which have no septa between cells (coenocytic).
- Some species thrive as parasites on plants, insects, or amphibians, while others are saprobes.

4- Dimorphism (i.e. existing in two forms)

Some fungi are capable of alternating between a mycelial growth form and a unicellular yeast phase. This change in growth form is often in response to some change in environmental conditions. This phenomenon is exhibited by several species of fungi that are pathogenic in humans, e.g. *Paracoccidioides brasiliensis*.These fungi are called dimorphic fungi, because they have "two forms." For example, the fungus *Histoplasma capsulatum*, which causes the disease histoplasmosis, is thermally dimorphic; it has two forms that are dependent on temperature. In temperatures of about 25°C, it grows as a brownish mycelium, and looks like a mass of threads. At body temperature (37°C in humans), it grows as single, round yeast cells.

Introduction to the Structure of Hyphae

Each hypha is: essentially a tube - consisting of a rigid wall and containing protoplasm tapered at its tip, this is the region of active growth (i.e. the extension zone).



- ❖ Some fungi possess septa at regular intervals along the lengths of their hyphae, in others, cross-walls form only to isolate old or damaged regions of a hypha or to isolate reproductive structures.
- ❖ Some septa possess one of more pores; such septa divide up the hyphae into a series of interconnected hyphal compartments, rather than separate, discrete cells.
- ❖ The plasma membrane is closely associated with the hyphal wall and in some regions, may even be firmly attached to it making it difficult to plasmolyse hyphae.
- ❖ Each hyphal cell or compartment normally contains one or more nuclei. In species whose septa possess a large central pore, the number of nuclei within a hyphal compartment won't remain static because the nuclei are able to pass between adjacent compartments, via the central septal pore.

- ❖ Cytoplasm contains a well-developed endoplasmic reticulum and contains either many smaller vacuoles, or one large vacuole.
- ❖ Mitochondria and many food particles made up glycogen, oil droplets and lipids, other cell organelles include ribosomes, microbodies and crystals are also common.
- ❖ The growing tip is structurally and functionally very different from the rest of the hypha.
- ❖ There are no major organelles at the extreme tip, at the extreme tip there is an accumulation of membrane bound vesicles - the apical vesicular cluster (complex) (AVC) which plays an important role in apical growth.
- ❖ Vacuoles may be visible in sub-apical hyphal compartments although small at first, they grow larger and merge with one another; they store and recycle cellular metabolites, e.g. enzymes and nutrients.
- ❖ In the oldest parts of the hypha the protoplasm may breakdown completely, due either to autolysis (self-digestion) or in natural environments heterolysis (degradation due to the activities of other microorganisms).

Hyphal aggregation

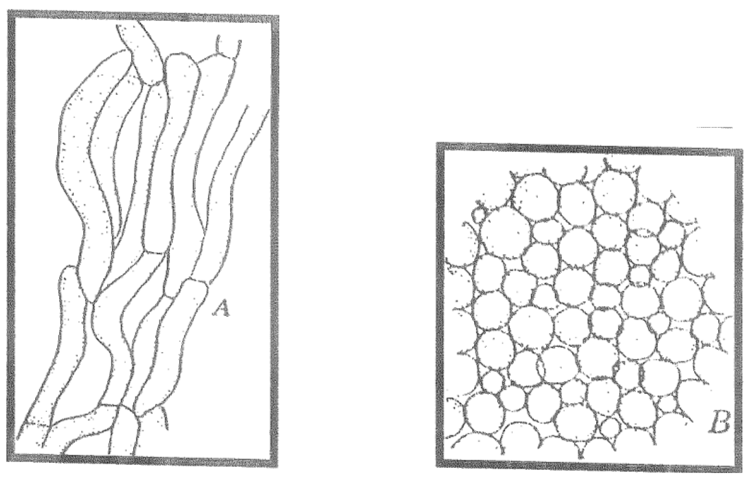
Many mycologists mentioned that mycelium in most of the true fungi gets organized into loosely, or compactly fungal tissue called plectenchyma which contains mainly two types as follows:

A- Prosenchyma

The hyphae remain arranged loosely but parallel to one another. This type is common in the fruiting bodies of some Asco and Basidiomycota and the main structure of the rhizomorphs

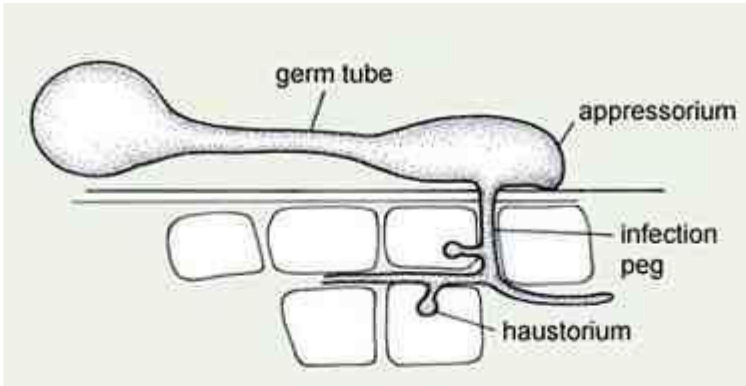
B- Pseudoparenchyma

The hyphae remain arranged compactly and therefore loose their individuality. The hyphal cells are oval or isodiametric. It is considered as the main structure of different fungal fruiting bodies.



Haustoria: (Haustor = drinker)

The mycelium of parasitic fungi may grow on the surface of the host and in this case, it is known as ectoparasites which they have special out growths to serve as hold fasts, or organs of attachment called **appressoria**. Haustorium may be knob-like, clavate or branched like a root system. Fungi that penetrate the host and develop their mycelia within the tissues called endoparasites and these mycelia may be restricted to small area as in leaf spots or may be distributed throughout the plant as in case of wilt diseases. The mycelium in this case is intercellular, lying between the cells, or intracellular lying within the cells.



Hyphal Growth

We already know that the growing hyphal tip is structurally and functionally different from the rest of the hypha but, the hyphal tip (like the rest of the hypha) is surrounded by a wall although the wall may be thinner and simpler in structure than the mature lateral wall of the hypha further back.

The growth of a hypha is closely linked to the presence of vesicles which form the apical vesicular cluster (AVC) when a hypha stops growing, these vesicles disappear but, when growth of the hypha resumes, the vesicles reappear.

The position of the vesicles is linked to the direction of growth of a hypha: -

1) When a hypha is growing straight ahead, the vesicles are positioned in the center of the hyphal tip.
2) Movement of the vesicles to the left or right side of the hyphal tip is accompanied by a change in direction of growth of the hypha.

Vesicles of the AVC contain:

- Wall precursors - the sub-units or building blocks of the wall polymers - e.g. uridine diphosphate N-acetylglucosamine, the sub-unit of chitin.
- Wall lytic enzymes - which help breakdown and separate wall components - e.g. chitinase, glucanase.
- Wall synthase enzymes - which help assemble new wall components and so increase the size of the wall - e.g. chitin synthase, glucan synthase.

Two models have been proposed to explain the mechanisms of apical growth, they differ in whether or not wall lytic enzymes are necessary.

Model 1- involvement of wall lytic enzymes:

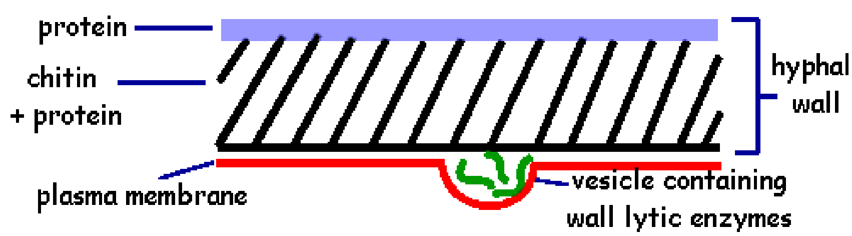
According to this model, if the hypha is going to be able to extend at its tip, there will have to be:

1) Some softening (lysis) of the existing wall, and
2) the synthesis and incorporation of new wall material.

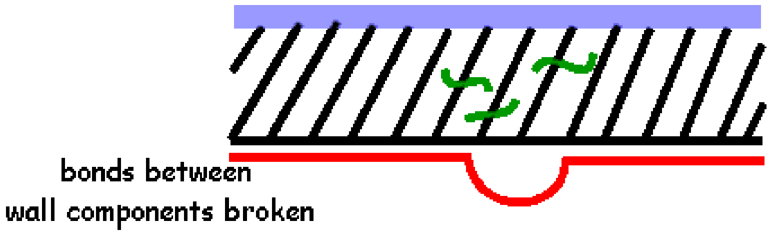
But these processes will have to be finely balanced. Otherwise, the wall may become too weak or too rigid for further growth

The following series of diagrams helps illustrate what may happen:

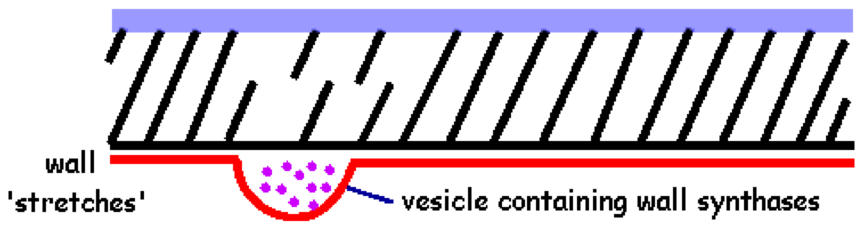
1- Vesicles containing lytic enzymes or wall precursors move through the cytoplasm towards the hyphal tip, where they fuse with the plasma membrane, releasing their contents into the wall.



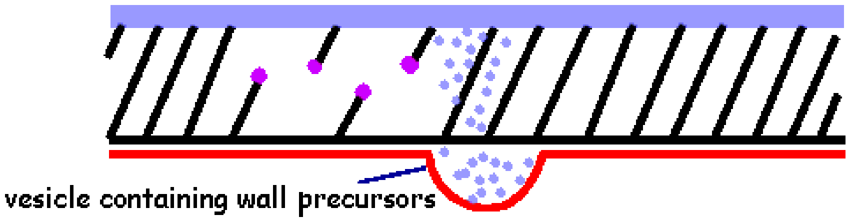
2- The lytic enzymes released into the wall attack the polymeric fibrils.



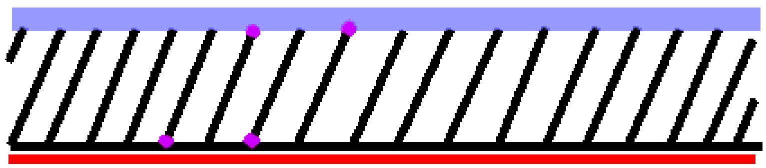
3- The weakened fibrils stretch out and become separated from one another due to the turgor pressure of the protoplasm.



4- Synthase enzymes and wall precursors build new fibrils and synthesize additional amorphous components of the wall.



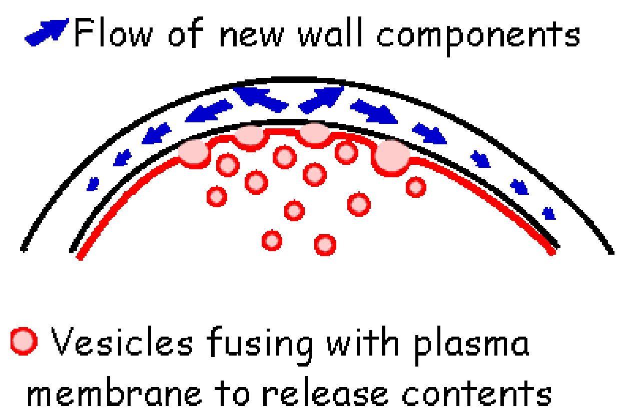
5- The surface area of the hyphal wall increases. Fusion of the vesicles with the plasma membrane ensures that the former contribute to the increase in surface area of the latter.



<u>Model 2</u>- steady state:

According to this model the lytic enzymes are not involved in apical growth, because the newly formed wall at the extreme tip of the hypha is viscoelastic (essentially fluid).

So that as new wall components are added at the tip, the wall flows outwards and backwards. The wall then rigidifies progressively behind the tip by the formation of extra chemical bonds.

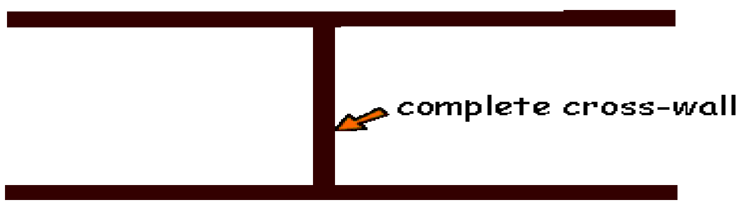


Septa (Function and type)

Septa (cross-walls) can be seen by light microscopy, but electron microscopy has revealed that several different types of septa exist among the major taxonomic groups of fungi.

Oomycota and Zygomycota

- In general, the hyphae of fungi belonging to these groups are not regularly septate (although there are some exceptions).
- But septa in the form of complete cross-walls are formed to isolate old or damaged regions of the mycelium or to separate reproductive structures from somatic hyphae.



Ascomycota and some mitosporic fungi

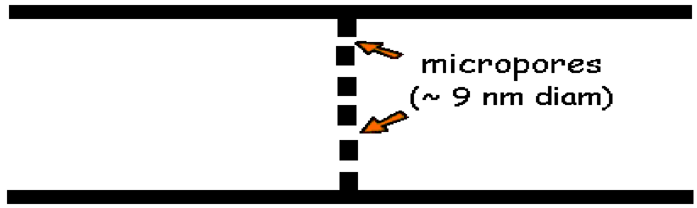
- Hyphae of fungi belonging to these groups possess perforated septa at regular intervals along their length.
- The septum consists of a simple plate with a relatively large central pore (50-500 nm diameter), this allows cytoplasmic streaming (the movement of organelles, incl. nuclei) between adjacent hyphal compartments.
- Cytoplasmic streaming enables sub-apical and intercalary (central) compartments of young hyphae to contribute towards growth of the hyphal tip, transporting nutrients and essential enzymes to the apex, so maximizing the capacity for somatic growth.

- Associated with each septum are spherical, membrane-bound organelles called woronin bodies that: -
    - Are composed of protein.
    - Remain close to the septal pore and tend not to be disturbed by the cytoplasmic streaming taking place.
    - Tend to be of the same or larger diameter than the septal pore and are, therefore, capable of blocking the pore.
    - Will block the septal pore if the adjacent hyphal compartment is damaged or ageing and becoming highly vacuolated.
- Not all fungi belonging to the Acomycota possess woronin bodies, some possess large hexagonal crystals of protein in the cytoplasm that can serve the same function, i.e. they can seal the septal pores of damaged or ageing hyphae.

Some other mitosporic fungi

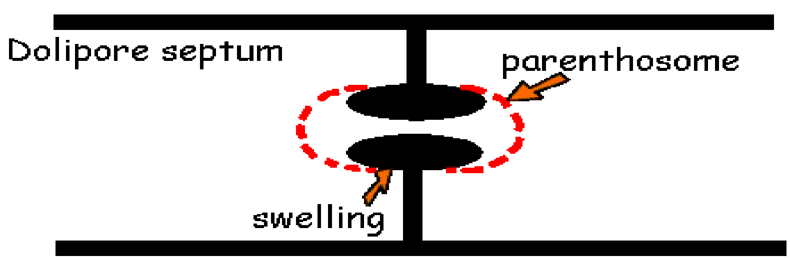
- Many mitosporic fungi possess septa with a single central pore, like that observed in the Ascomycota.
- But other mitosporic fungi may possess multi-perforate septa, e.g. the septa of *Geotrichum candidum* (illustrated below) possess characteristic micropores (approx. 9 nm diameters).
- The number of pores in each septum can vary up to a maximum of approx. 50.

- These micropores allow cytoplasmic continuity between adjacent hyphal compartments but are too small to allow cytoplasmic streaming to occur to the extent observed in fungi possessing larger septal pores.



Basidiomycota:

- The most complex type of septum is found in fungi belonging to the Basidiomycota.
- Each septum is characterized by a swelling around the central pore (dolipore) and a hemispherical perforated cap (parenthosome) on either side of the pore.
- The perforated parenthosome allows cytoplasmic continuity but prevents the movement of major organelles.
- The plasma membrane lines both sides of the septum and the dolipore swelling, but the membrane of the parenthosome is derived from endoplasmic reticulum.



Functions of septa

- Act as structural supports: The addition of plate-like cross-walls to what is essentially a long tube-like structure (hypha) will help stabilize it.
- Act as the first line of defence when part of a hypha is damaged
    - Large-pored septa that have woronin bodies or large proteinaceous crystals associated with them have the advantage that cytoplasmic streaming can occur between adjacent compartments.
    - But at the same time a mechanism exists for rapidly sealing the septal pore under conditions of stress (e.g. if the hypha is damaged) thereby helping protect the mycelium.
- Facilitate differentiation in fungi
    - Septa can isolate adjacent compartments from one another so that different biochemical and physiological processes can occur within them, these may result in differentiation of the hyphae into specialized structures, such as those associated with sporulation.
    - It's unlikely to be coincidental that the most complex and highly differentiated sporulating structures we see are those produced by fungi possessing the most complex types of septa, i.e. fungi belonging to the basidiomycota.

Importance of Fungi

Fungi are important because they are:

- ❖ Agents of biodegradation and biodeterioration
- ❖ Responsible for most of plant diseases and several diseases of animals (including humans)
- ❖ Used in industrial fermentation processes
- ❖ Used in the commercial production of many biochemicals

- Cultured commercially to provide us with a direct source of food
- Used in bioremediation
- Beneficial in agriculture, horticulture and forestry.

Fungi are agents of biodegradation and biodeterioration:

Saprotrophic fungi utilise dead organic materials as sources of nutrients and are responsible for the biodegradation of organic materials in our environment, particularly plant materials in the form of leaf litter and other plant debris. Such fungi play a vital role in recycling essential elements, particularly carbon. Fungi are very effective and efficient biodegraders because of the wide range of extracellular enzymes they produce, which are capable of degrading complex polymers, such as cellulose, proteins and lignins.

Unfortunately, their excellent biodegradative abilities mean that many saprotrophic fungi can contaminate our food sources or destroying many consumer goods we manufacture from natural raw organic materials. For example, some saprotrophic fungi are particulalry dangerous contaminants of seeds and grains because they produce metabolites known as mycotoxins (fungal toxins), when ingested mycotoxins cause toxic or carcinogenic symptoms in humans and other animals. Some *Aspergillus* species produce a group of chemically related mycotoxins called aflatoxins.

A second example is provided by the 'dry rot' fungus, *Serpula lacrymans*, which attacks wood and can be a very costly, potentially dangerous and certainly most unwelcome visitor when it attacks timbers used in the construction of buildings (e.g. floor and wall joists or roof timbers).

Fungi are responsible for most of plant diseases and several diseases of animals (including humans):

For example, *Phytophthora infestans* is the causal agent of late blight disease in potatoes. The disease reached epidemic proportions across Europe in the mid 19th century and resulted in the Irish potato famine.

Some fungi are actively parasitic in humans and other animals, while others induce severe allergic reactions if their spores are inhaled resulting in attacks of asthma or hay fever.

Fungi are used in industrial fermentation processes:

Yeasts and mycelial fungi are used in a variety of industrial fermentation processes. For example, *Saccharomyces* species are used extensively in brewing beers and wines, as well as in bread making. Fungi are also used in the commercial production of many biochemicals, e.g. *Aspergillus niger* is used in the large-scale commercial production of citric acid.

Many fungi provide us with a direct source of food:

Some yeasts and mycelial fungi are cultured on a large scale and then undergo further processing to provide various protein-rich food products for human or livestock consumption. For example, Quorn mycoprotein is produced commercially from the mycelial fungus *Fusarium venanatum*. The mycelium is harvested and processed to provide a protein rich meat substitute in a range of convenience foods. Some species are cultivated for their edible fruiting bodies, e.g. the basidiocarps of *Agaricus bisporus*.

Fungi are used in bioremediation:

Some species of yeasts and mycelial fungi are used in processes aimed at reducing the concentrations and toxicity of waste materials, particularly from industrial processes, before those wastes are released into the environment, this process known as bioremediation. For example, *Aspergillus niger* is used to breakdown tannins in tannery effluents to less toxic compounds.

Some fungi prove highly beneficial in agriculture, horticulture and forestry:

For example, some species form symbiotic relationships with the roots of plants, known as mycorrhizas. Mycorrhizas significantly improve plant growth and vigour, resulting in increased yields in crop plants.

Other fungal species are used in the biological control of insect and nematode pests, weeds and pathogenic microorganisms. For example, the fungus *Beauvaria bassiana* is used to control several insect pests.

Growth of Fungi

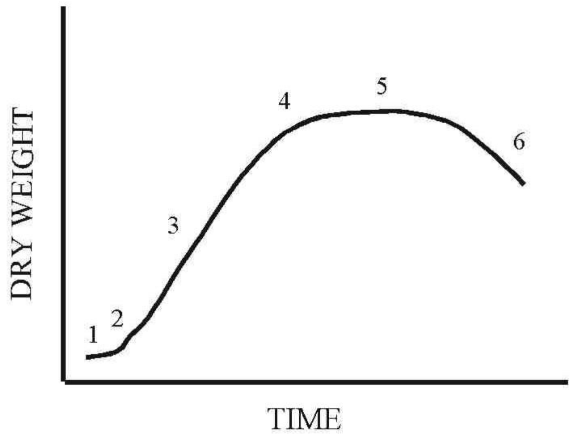
Fungal growth may be restricted or unrestricted. Unrestricted fungal growth occurs when the substrate contains an excess of all growth factors. During unrestricted growth, the total hyphal length and the number of tips of a mycelium increases indefinitely. In nature, unrestricted growth may only be possible within a short time due to unfavourable growth conditions. Restricted growth occurs when fungus grow on a solid substrate for example a drywall, eventually results in conditions such as nutrient depletion, change in pH at the center of the colony which are less favourable for growth than was initially the case. If there is no competition with other microorganisms, growth of the hyphae on the peripheral ring occurs at approximately maximum growth rate but growth proceeds at below maximum growth rate elsewhere in the colony, often falling to zero or near zero at the colony center, i.e., some parts of the fungus would be actively growing while others would not be growing at all or would be dead.

Phases of growth

A- Unicellular fungi

1- **lag phase**, during this phase unicellular fungi (yeasts) adapt themselves to growth conditions. During the lag phase of the fungal growth cycle, synthesis of DNA, enzymes and other molecules occurs. It is the period where the individual cell are maturing and not yet able to divide. The length or shortness of this phase depend on many factors such as:
    a) Age and size of fungal inoculum
    b) The kind of the medium
    c) Environmental factors e.g temperature.
2- **Phase of accelerated growth** the cells start to divide and new protoplasm is formed from the nutrient found in the medium, and during this phase the time required for synthesis new cells decrease.
3- **Log phase** (sometimes called the logarithmic phase or the *exponential phase*) is a period characterized by cell doubling. The number of new yeast appearing per unit time is proportional to the present population. For this type of exponential growth, plotting the natural logarithm of cell number against time produces a straight line.
4- **Phase of decline acceleration**: During this phase the rate of growth is decreased because the time required for synthesis new cells increase.
5- **Stationary phase** is often due to a growth-limiting factor such as the depletion of an essential nutrient, and/or the formation of an inhibitory product such as an organic acid. Stationary phase results from a situation in which growth rate and death rate are equal. The number of new cells created is equal to the rate of cell death. The result is a “smooth,” horizontal linear part of the curve during the stationary phase.

6- **Death phase** (Decline phase). This could be due to lack of nutrients, a temperature which is too high or low, or the wrong living conditions.



B- Filamentous Fungi

1- **Lag phase**

Once the growth conditions become favourable for the fungal propagules (i.e., viable spores or mycelial fragments) to germinate, new transport systems must be induced before growth commences. Thus, growth starts slowly and accelerates gradually. This phase is referred to as the lag phase.

2- **Exponential or log phase**

Exponential growth occurs only for a brief period as hyphae branches are initiated, and then the new hypha extends at a linear rate into un-colonized regions of substrate. The biomass of the growing fungus doubles per unit time. If the nutrients are in excess growth remains constant during the exponential phase.

3- **Stationary phase**

As soon as the nutrients are depleted or toxic metabolites are produced growth slows down or is completely stopped. The biomass increases gradually or remains constant. During the stationary phase, hyphal growth stops and, in some molds, cell differentiation occurs, resulting in spore formation. During this process nutrients are transferred from the vegetative mycelium to the developing spores. The spores are dispersed by air movement to other areas of the building where they can start new mold growth once the conditions for growth are favourable.

4- **Death phase**

During the death phase, the mycelium eventually dies off. The death phase is usually accompanied by breakdown of the mycelia through self-digestion. Some fungi form spores by fragmentation of the hyphae.

Reproduction in Fungi

Fungi reproduce asexually as well as sexually. The asexual cycles are repeatedly made during the season. In the asexual reproduction certain types of spores are formed without involving the fusion of nuclei or sex cells. In the sexual process is usually made once a year and it is only induced by specific unfavourable conditions which should be the fusion between two types of sex cells (gametes) take place.

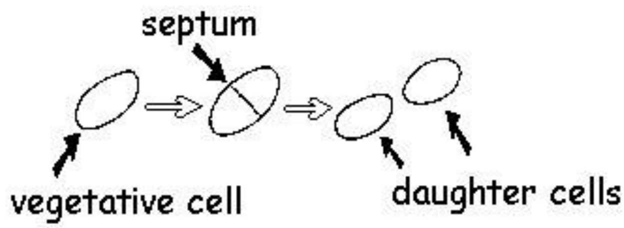
Asexuall reproduction

It is the most important reproduction type in fungi. They are repeatedly made during the season, as it results in the production of uncountable units. This asexual reproduction process may take in one of the following ways:

A-Vegetatively:

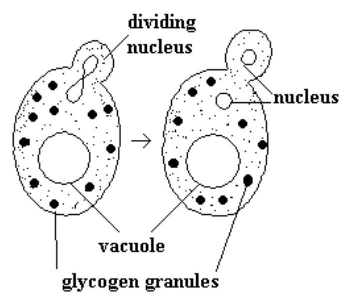
1- Bifission “Fission yeast”

It is a process occur in unicellular forms which splitting of the unicellular somatic cells to two equal cells



2- Budding "budding yeast"

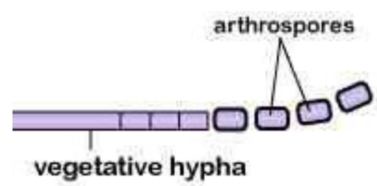
In budding, an outgrowth (bud) is developed from mature cell; the bud either separate from the parent cell and behaves as a new individual or remain attached to the mother cell to produce chains of buds.



3- Fragmentation

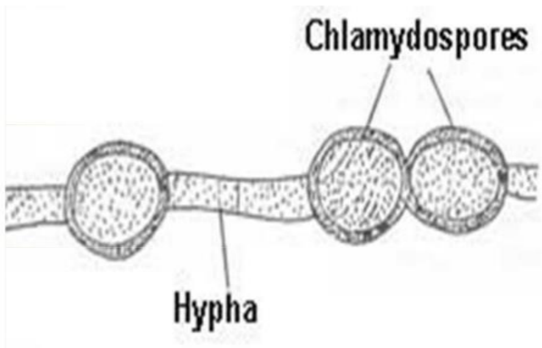
In which the fungi are split into fragment, each fragment develops into mature, fully grown organism.

- **Arthrospres:** In which the hypha breaks up (at the favourable conditions) into separate thin walled units called arthrospores or Oidia (Greek= small egg).



Coccidioides immitis

- **Clamydosores:** Sometimes hyphal units (cell or compartment) are enlarges rounds up and develops a thickened, often pigmented wall, Contain dense cytoplasm and nutrient storage compounds. May be apical or intercalary (central) chlamydospores according their positions. Chlamydospres are formed during unfavourable or abnormal conditions



B- Sporulation:

It is the most common methods in fungi, spores are minute units vary in color, size, and shape. On the basis of the variations in characters of spores is made, the most of systems of fungi classification. Some fungi are homospory (i.e. producing one type of spores), others are heterosporous (producing different types of spores) which may reach to four as in the case of *Puccinia.*

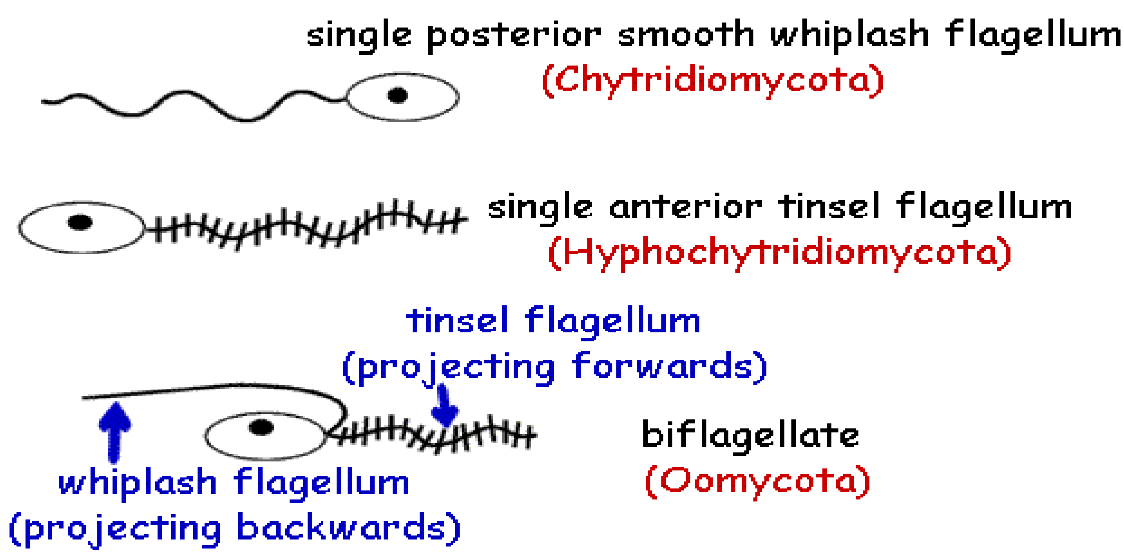
a- Endogenous spores

are sporangiospores formed and contained within a sporangium and formed as a result of the cleavage of protoplasm around nuclei. Followed in some cases by formation of a wall around each nucleate portion of protoplasm. There are two types of endogenous spores: -

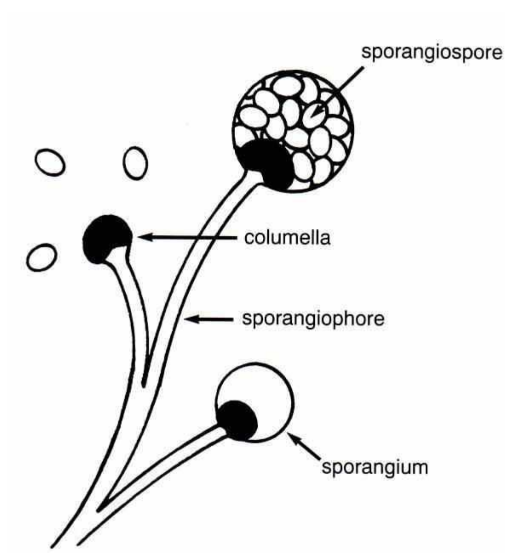
Zoospores (motile): Which formed in many lower fungi, especially aquatic form. Zoospores are uni or biflagellate which enclosed in zoosporangium.

- The protoplasm of zoospores is not surrounded by a wall; in some respects they resemble flagellate protozoa.

- Because zoospores are motile, the fungi that produce them will require water at some stage during their life cycle.
- Three different types of zoospore distinguish the Chytridiomycota, Hyphochytridiomycota and Oomycota.



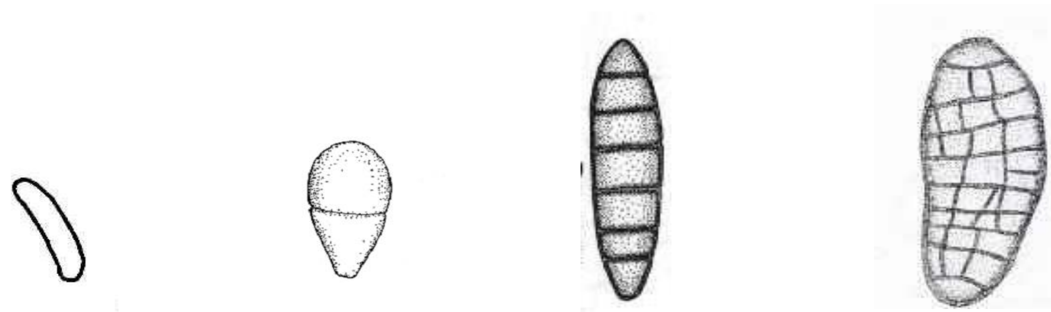
Aplanospoes (non-motile or true sporangispores): Formed in sac like structure called sporangium. The protoplasm of sporangiospores is surrounded by cell wall.



b- Exogenous spores:

These spores called conidia (single = conidium), borne externally on specific locus of vegetative hyphae or specialized stalks or branch called conidiophores. Conidia are produce as solitary (single), in balls (clusters) or in chains either acrpetalae or basipetalae.

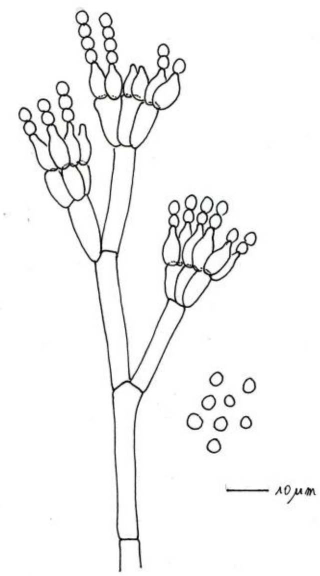
Conidia differ in shape (spherical, subspherical, ovate, pyriform, clavate, …etc.), size, color (hyaline or pigmented), septation types (amero, didymo, phragmo, dictyospores).



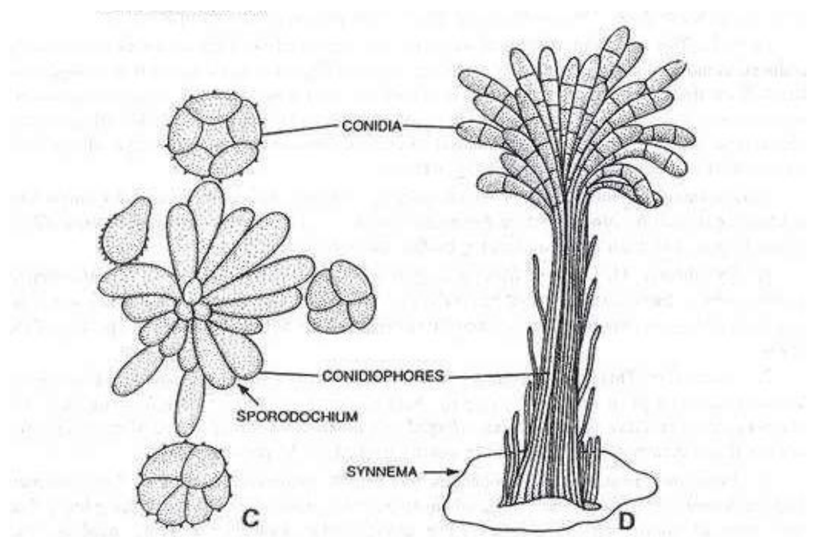
Amerspore **Didymospore** **Phragmospore** **Dictyospore**

Conidiophores

The conidia are produced directly on single conidiophores (the most common form) or as synnemata, or coremia special structures such long bundles of conidiophores or cushion-like sporodochium flattened bundles of conidiophores



Single conidiophore



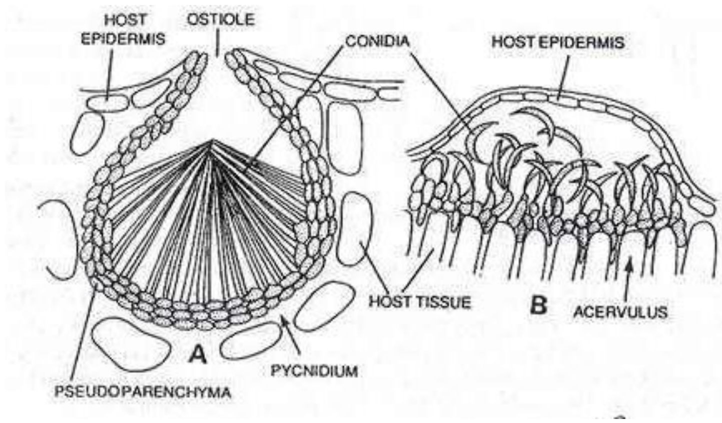
Sporodochium

Synnenmata

In some cases, conidiophores and conidia are developed within covered conidiomata (fruiting bodies). These fruiting bodies are consisting of pseudoparenchymatous structures and these mainly two types as follows:

Pycnidium: A flask-shaped structure with conidiophores developing from cells of the pycnidial wall. e.g. *Phoma* species.

Acervulus: In which, fungal hyphae aggregate and form a flat fertile layer of short conidiophores that produce many conidia. The pressure of accumulating conidia, and often of accessory of mucilage, eventually splits the host epidermis and allow the conidia to escape.



Sexual Reproduction

The sexual process is usually made once/year and it is only induced by unfavourable conditions. Fungal sex organs known as gametangia

Stage of sexual reproduction

Usually sexual reproduction process should pass through three main different stages as follows:

1- Plasmogamy (Cytogamy)

It is union of two protoplasts of haploid nuclei (gametes) in one cell, takes place by means of the different methods. This phase may be very short as in case of yeasts or long time e.g. *Puccinia gramminis*.

2- Karyogamy

In which the two nuclei of gametes are fused together producing zygote (2n). This phase does not always take place immediately after plasmogamy but may be delayed.

3- Meiosis

In this stage, a reduction in the number of chromosomes of zygote (2n) take place, forming at the end haploid (n) sexual spores.

Types of sexual reproduction

The gametangia may be morphologically distinguished and these are heterogametangia. Sometimes the gametangia are in distinguishable and are, thus, known as isogametangia.

1- Iso or homogametangia

   In which union or fusion take place between indistinguishable gametangia and gametes are called isogametes

2- Aniso or heterogametangia

   In which union take place between one large (female) and one tiny (male) gametes. The gametes are morphologically distinguished.

3- Oogamy & Ascogamy

   In some cases, these hetergametes are developing with sex organs. In oomycetes, the male gametangium called anthredium and the female gametangium oogonium which contains one ovum or more.

   In case of Ascomycetes, the antheridium (male) and the ascogonium (female) have numerous male and female nuclei.

Myxomycota

Division Myxomycota comprises the plasmodial slime molds. The slime molds are unicellular, colonial, and multicellular at different stages of their life cycles. They thrive in moist environments with bacteria, usually on decaying organic matter.

Class Myxomycetes:

The Myxomycetes, or true slime molds often designated as slime molds, or slime fungi, or Mycetozoa as they are called, are a unique group of fungus-like organisms concerning whose origin and relationships there is no common agreement. They exhibit characteristic of both animals and plants.

Their somatic phase of multinucleate mass of protoplasm without cell wall exhibiting creeping movement, known as plasmodium, is definitely animal-like, resembling a giant amoeba in its structure and in its physiology. The reproductive process of the Myxomycetes, however, is plantlike producing spores with definite cell walls.

The plasmodium eats by extending pseudopodia, and, though large and branching, it is a continuous mass of cytoplasm with many nuclei. The thin tubes of the plasmodium optimize surface area to increase uptake of nutrients, oxygen, and water, and these are distributed by pulsing and sending streams of cytoplasm throughout the organism.

When food becomes scarce, the plasmodium differentiates into numerous reproductive structures, from which amoeboid or flagellated cells will emerge when the food supply decrease.

Myxomycota producing haploid spores which contain cell wall composed from cellulose.

Economic Importance of Myxomycota:

The Myxomycetes are of relatively little economic importance, but they have been the subject of intensive laboratory studies. They contribute to the carbon and nitrogen cycles by using various organic matter including bacteria as food.

They provide a large amount of protoplasm free from cell walls which has been used as an ideal medium to solve variety of fundamental problems of biSome of the areas of studies are: the structure and chemical composition of protoplasm, the velocity of the protoplasmic movement, the chemical changes governing the production of sporangia and spores, the behaviour of nuclei and chromosomal changes during plasmodial growth, various aspects of plasmodial compatibility, etc.ochemists, biophysicists, mycologists and even the geneticists.

Occurrence of Myxomycota:

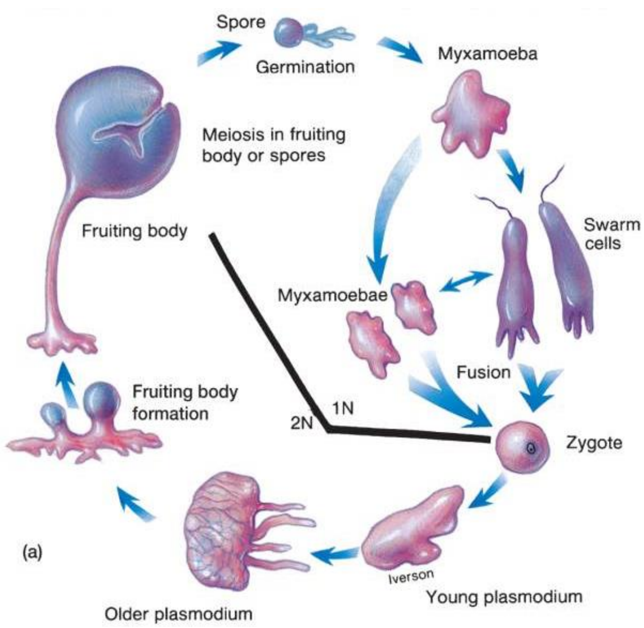
The Myxomycetes are common but inconspicuous inhabitants of moist dead wood, rotting logs, damp soil, leaf mold, moist sawdust, bark of trees, decaying fleshy fungi, or other organic matter. They often spend most of their lives within the substrate and emerge only when about to produce sporangia. Following periods of rainy weather they may occur on leaves of grasses or other plants on lawns.

Life cycle

Life cycle of slime moulds chracterized by alteration of generation in which appear haploid phase and diploid phase.

Life cycle of slime mold starts with the germination of a meiospore under favourable condition giving swarm cells and myxamoebae under wet condition. Fusion between two swarm cells or myxamoebae followed by karyogamy results in formation of zygote which is uninucleate, diploid and amoeboid in form. Then zygote germinate in size with successive divisions of the diploid parent nucleus forming multinucleate amoeboid mass of protoplasm called the young plasmodium. Favourable temperature, abundant moisture and food, these factors favor its growth, movement and reproduction.

Normally the plasmodium after attaining a certain size and stage of maturity enters the reproductive phase in which, the slime layer dries and the diploid proplast concentrates at a few points forming a mound like structure. The later grows into a stalked sporangium. The diploid protoplasm of the sporangium cleaves into numerous young spores each of which has a diploid nucleus. The diploid nuclei of the young spores undergo meioses to form meiospores (haploid nucleus). When mature meiospores are released, dispersed by wind and falling on sutitable substatum the meiospores germinates to release swarm cells or myxamoebae which fuse in pairs to form zygote.



Life cycle of slime moulds

Eumycetes (True fungi)

The members of the division Eumycota are called true fungi. It is a very large group consists of approximately 75,000 known species, but this number should be much more as more species are regularly being added in the list due to the discovery of new species from different corners of the world.

The thalli of Eumycota usually do not posses Plasmodia or pseudoplasmodia. Members are unicellular or filamentous with definite cell wall. Spores of many fungi act as common conta-minants of our food. They cause diseases of both plants and animals including human beings. They are also useful in many respects.

Characteristics of Division Eumycota (True Fungi):

The important characteristics of the division Eumycota are:

1. The plant body is thalloid and commonly consists of profusely branched filament, the mycelium, except a few unicellular members (Saccharomyces etc.). In filamentous body, unit branch of the mycelium is called hypha (pi. hyphae).

2. The mycelial plant body may be aseptate i.e., coenocytic (lower fungi, Mastigomycotina and Zygomycotina) or septate (higher fungi, Ascomycotina, Basidiomycotina and Deuteromycotina).

3. Septa, when present, are perforated. The pores are of different types: micropore (Geotrichum), simple pore (most of the Ascomycotina and Deuteromycotina) or dolipore (Basidiomycotina except rusts and smuts).

4. The hyphal wall is made up of fungal cellulose i.e., chitin; but in some lower fungi (members of Oomycetes), cell wall composed of cellulose or glucan.

5. Growth of hyphae is apical.

6. The cells are haploid, dikaryotic or diploid. Diploid phase is ephemeral (short lived). The dikaryotic phase persists for longer period in higher fungi (members of Basidiomycotina).

7. Most of the fungi are eucarpic in nature.

8. Reproduction takes place by all the three means: vegetative, asexual and sexual. (Sexual reproduction is absent in Deuteromycotina).

9. Spores are either motile (Mastigomycotina) or non-motile (in rest members).

10. During sexual reproduction, plasmogamy takes place through: Gametic copulation (Synchytrium), Gametangial contact (Pythium, Phytophthora), Gametangial copulation (Rhizopus, Mucor etc.), Spermatization (Puccinia) and Somatogamy (Agaricus, Polyporus).

11. Progressive reduction of sex is observed from lower to higher form.

12. Parasitic members cause diseases having both harmful and useful activities.

Classified by method of reproduction

1. Zygomycetes 2. Basidomycetes 3. Ascomycetes 4. Deuteromycetes

1. Zygomycetes

Commonly known as bread moulds, these are fast growing, terrestrial, largely saprophytic fungi. Hyphae are coenocytic and mostly aseptate. Asexual spores include chlamydoconidia, conidia and sporangiospores. Sporangiophores may be simple or branched. Sexual reproduction involves producing a thick-walled sexual resting spore called a zygospore. Medically important orders and genera include:

1. Entomophthorales: Conidiobolus and Basidiobolus are involved in subcutaneous zygomycosis

2. Mucorales: Rhizopus, Mucor, Rhizomucor, Absidia are involved in subcutaneous and systemic zygomycosis (formerly called Mucormycosis)

2. Basidomycetes

They exist as saprobes and parasites of plants. Hyphae are dikaryotic and can often be distinguished by the presence of clamp connections over the septa. Sexual reproduction is by the formation of exogenous basidiospores, typically four, on a basidium. Occasional species produce conidia but most are sterile. Genera of medical importance include: Cryptococcus neoformans, Mushroom poisoning by Aminita.

3. Ascomycetes

They exist as saprophytes and parasites of plants. Hyphae are septate with simple septal pores. Asexual reproduction is by conidia. Sexual reproduction is by the formation of endogenous ascospores, typically 2 eight, in an ascus. Examples of sac-fungi are morels, truffles, cup fungi and powdery mildews. Example: Aspergillus, Claviceps, Neurospora.

4. Deuteromycetes

Deuteromycetes are also known as Fungi Imperfecti because of absence of sexually reproducing forms (teleomorph or perfect stage). As their teleomorph continue to be discovered, they would be classified among the previous categories, until then this remains an artificial and heterogeneous group. There are three classes of Fungi Imperfecti.

1. Blastomycetes: These include asexual budding forms of Cryptococcus, Candida,. Depending on the presence of melanin in their cell walls, they may be non-dematiaceous or dematiaceous.

2. Hyphomycetes: A class of mycelial moulds which reproduce asexually by conidia on hyphae. Hyphae are septate.

MODERN TAXONOMY

Systematics is field of biology dealing with diversity and evolutionary history of life,. It includes

1-Taxonomy: DINC is the branch of systematics concerned with (Description ,Identification , Nomenclature,Classification)

2-Phylogeny is the branch of systematics concerned with Determine Evolutionary History of Life .involes monophyletic and polyphyletic.

monophyletic group is a taxon (group of organisms) which meaning that it consists of an ancestral species and all its descendants. All fungi Monophyletic groups contain all the descendents from a common ancestor.. or all the branches come from a common ancestor and no branches from another ancestor are included just because they converged on a similar character.

Poly phyletic group is a taxon (group of organisms) which meaning that it consists of more than one ancestral species and all its descendants.

History of taxonomy of mycology

Until the latter half of the twentieth century fungi were classified in the Plant Kingdom (strictly speaking into the subkingdom Cryptogamia, **Division 1 : Fungi subdivision Eumycotina)** and were separated into four classes: the Phycomycetes, Ascomycetes,Basidiomycetes, and Deuteromycetes (the latter also known as Fungi Imperfecti because they lacked a sexual cycle).

Subdivision 2 Myxomycotina involves The slime moulds These traditional groups of 'fungi' were largely defined by the morphology of their sexual organs, whether or not their hyphae had cross walls (septa), and the ploidy (degree of repetition of the basic number of chromosomes) of nuclei in their vegetative mycelium.

Around the middle of the 12th century the two major kingdoms

The prokaryotic kingdom (bacteria and Archea) and **the eukaryotic kingdom** (plants, animals, fungi, protozoa and algae). At least 7 kingdoms are now recognized: Eubacteria, Archaebacteria, Animalia, Plantae, Eumycota, Stramenopila (Chromista), Protoctista (Protozoa, Protista).

The Scientists in classification of fungi

1-Aleopoulus in 1962 in 2nd edition from his book (Introductory mycology) was classified mycology into Division : Mycota Which involves 2 subdivisions

Subdivision 1: Myxomycota

Subdivision 2 : Eumycotina which involves 9 classes While in 1997 Aleopoulus reclassified in same title of book 3th edition classified mycology into Kingdom : **Mycetae** which involves 3 divisions

KINGDOM MYCETEAE (Fungi, including slime molds)

DIVISION **GYMNOMYCOTA**

Subdivision Acrasiogymnomycotina

Class Acrasiomycetes

Subdivision Plasmodiogymnomycotina

Class Protosteliomycetes

Class Myxomycetes

DIVISION 2 : MASTIGOMYCOTA

Subdivision Haplomastigomycotina

Class Chytridiomycetes

Class Hyphochytridiomycetes

Class Plasmodiophoromycetes

Subdivision Diplomastigomycotina

Class Oomycetes

DIVISION 3: AMASTIGOMYCOTA

Subdivision Zygomycotina

Class Zygomycetes

Class Trichomycetes

Subdivision Ascomycotina

Class : Ascomycetes

Subclass Hemiascomycetidae

Subclass Plectomycetidae

Subclass Hymenoascomycetidae

Class: (Pyrenomycetes)

Subclass Laboulbeniomycetidae

Subclass Loculoascomycetidae

Class Discomycetes

Subdivision Basidiomycotina

Class Basidiomycetes

Subclass Holobasidiomycetidae (Hymenomycetes)

Class Gasteromycetes

Subclass Phragmobasidiomycetidae

Subclass Teliomycetidae

Subdivision Deuteromycotina

Form-Class Deuteromyetes

Form-Subclass Blastomycetidae

Form-Subclass Coelomycetidae

Form-Subclass Hyphomycetida

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