PAPER – 1

MICROBIOLOGY, MYCOLOGY AND PLANT PATHOLOGY

UNIT - III

General Characteristics of Fungi

Introduction

The fungi are a group **of eukaryotic, non-vascular organism.** Which are of **diverse forms, sizes, physiology and reproduces** both by **sexual (meiotic) and asexual (mitotic) spores**.

The study of fungi is known as **mycology** and who study about fungus is known as **mycologist.**

General characteristics of Fungi

- **Nutrition**

(a) Saprophytes

They obtain food from dead and decaying organic matter. They secrete digesting enzymes to outside which digest the substratum and then absorb nutrients, e.g., *Mucor, Agarious. Rhizopus* (bread mould) etc.

(b) Parasitic:

They obtain food from living .They maybe facultative or obligate. Facultative parasites grow on a variety of tissues and often cause 'soft rot' of the tissue, e.g., *Ustilago.*
The obiigate- parasites absorb through specialized haustoria. The parasitic fungi that grow on surface of host cells and absorb food through haustoria are called ectoparasites or ectophytic parasites (e.g., *Mucor, Erisphae*). When parasitic fungi grow inside the host tissue arc called endoparasites or endophytic parasites (e.g., *Pythium, Puccinia*).

(d) Symbiotic:
They live in mutualistic relationship with another organism by which both are benefited. The two common examples are lichens and mycorrhiza.

Lichens are symbiotic associations between fungi and algae. The fungal partner is a member of ascomycetes or basidiomycetes that provides water and nutrients, while the algal partner is a green alga or cyanobacteria that prepares food by photosynthesis.

Mycorrhizas or mycorrhizae (fungus roots in Greek) are the mutualistic symbiotic associations between soil fungi and the roots of most plant species (95% of all plant families are predominantly mycorrhizal).

The two most common types of mycorrhizas are the ectomycorrhizas (ECM) and the endomycorrhizas (also known as arbuscular mycorrhiza, AM or VAM). The two groups are differentiated by the fact that the hyphae of ectomycorrhizal fungi do not penetrate the cell wall of the plant's root cells, while the hyphae of arbuscular mycorrhizal fungi penetrate the cell wall.

Reproduction:

Like most other thallophytes, fungi also reproduce by vegetative, asexual and sexual means. However, asexual reproduction is generally predominant Depending upon the involvement of the entire thallus or a part of it, the fungi may be holocarpic or eucarpic.

(i) Holocarpic:

In this category of fungi the entire thallus gets converted into one or more reproductive bodies. Hence, the vegetative and reproductive phase can never occur at the same time.

(ii) Eucarpic:

Most of the fungi are eucarpic. Here only a part of the thallus is involved in the development of reproductive organs and remaining thallus remains vegetative. In eucarpic fungi, vegetative and reproductive phases exist at the same time.

A. Vegetative Reproduction:

In this type of reproduction, a part of mycelium separate and forms a new individual. The various methods of vegetative reproduction are— fragmentation, budding, fission, sclerotia, rhizomorphs and oidia formation. In case of *Rhizopus a*nd *Coprinus* the hyphae break up into numerous fragments called oidia, each of which give rise to a new mycelium.

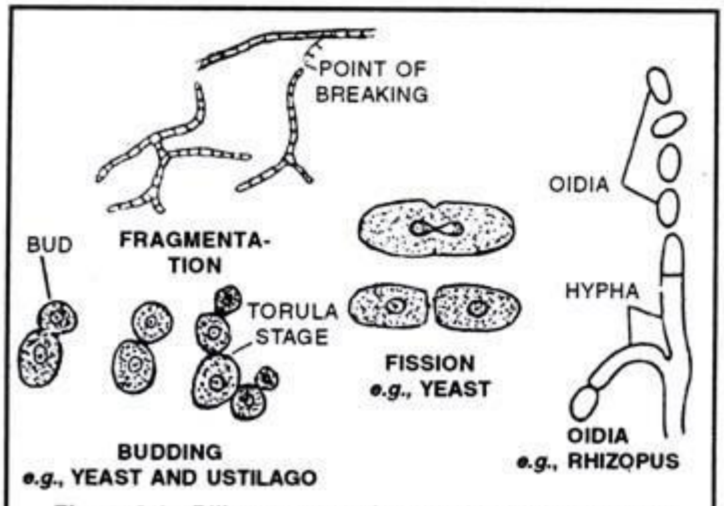

Figure 6.4 Different types of vegetative reproduction in

B. Asexual Reproduction:

It commonly occurs through spores, either motile or non-motile and form in a specialized part of mycelium. The various types of spores are: zoospores, sporangiospores (=aplanospores), conidia, oidia (arthrospores), chlamydospores, gemmae, ascospores, uredospores, basidiospores etc.

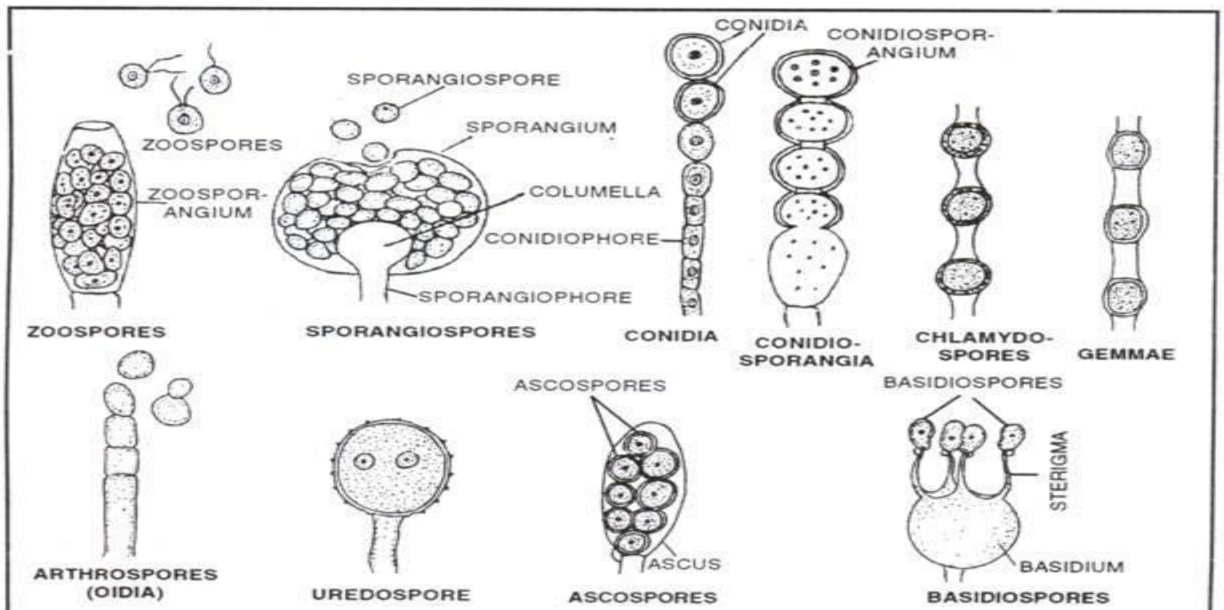

Figure 6.5 Various types of fungal spores.

C. Sexual Reproduction:

It involves the formation and fusion of gametes. Sexual reproduction found in all groups of fungi except deuteromycetes or fungi imperfecti. Sexual reproduction has three distinct phases i.e. plasmogamy (protoplasmic fusion), karyogamy (fusion of nuclei) and meiosis (reduction division of zygote).

The various methods of sexual reproduction in fungi are as follows:

(i) Planogametic copulation:

This is simplest type of sexual reproduction. In this process fusion of two gametes of opposite sex or strains takes place where one or both of the fusing gametes are motile (flagellated). It results in the formation of a diploid zygote.

This process is usually of three types:

(a) Isogamy:

In this process fusing gametes are morphologically similar and motile but physiologically dissimilar. These gametes are produced by different parents e.g. *Synchytrium.*

(b) Heterogamy:

When the fusing gametes are morphologically as well as physiologically different, the process is known as heterogamy. Heterogamous reproduction is of two types: anisogamy and oogamy. Anisogamy consists of the fusion of two motile gametes where the male gamete is small and more active than the female gamete, e.g., Allomyces. In oogamy the motile male gamete (antherozooid) fuses with the large, non-motile female gamete (egg or ovum), *Monoblepharis, Synchytrium* etc.

(ii) Gametangial contact:

In this process two gametangia of opposite sex come in contact with one another. The male gametangium (antheridium) transfer male nucleus or gamete into the female gametangium (oogonium) either through a pore at the point of contact or through a fertilization tube, e.g., *Phytophthora, Sphaerothera, Albugo, Pythium* etc.

(iii) Gametangial copulation:

In involves the fusion of entire contents of two gametangia to form a common cell called zygote or zygospore, e.g., *Mucor, Rhizopus.*

(iv) Spermatization:

Some fungi produce many minute, spore-like, single-celled structures called spermatia (nonmotile gametes). These structures are transferred through agencies like water, wind and insects to either special receptive hyphae or trichogyne of ascogonium. The contents migrate into receptive structure. Thus dikaryotic condition is established, e.g. *Puccinia.*

(v) Somatogamy:

This takes place in fungi where formation of gametes is absent. In such fungi, anastomoses takes place between hyphae and their somatic cells fuse to produce dikaryotic cells, e.g, *Agaricus*, *Peniophora* etc.

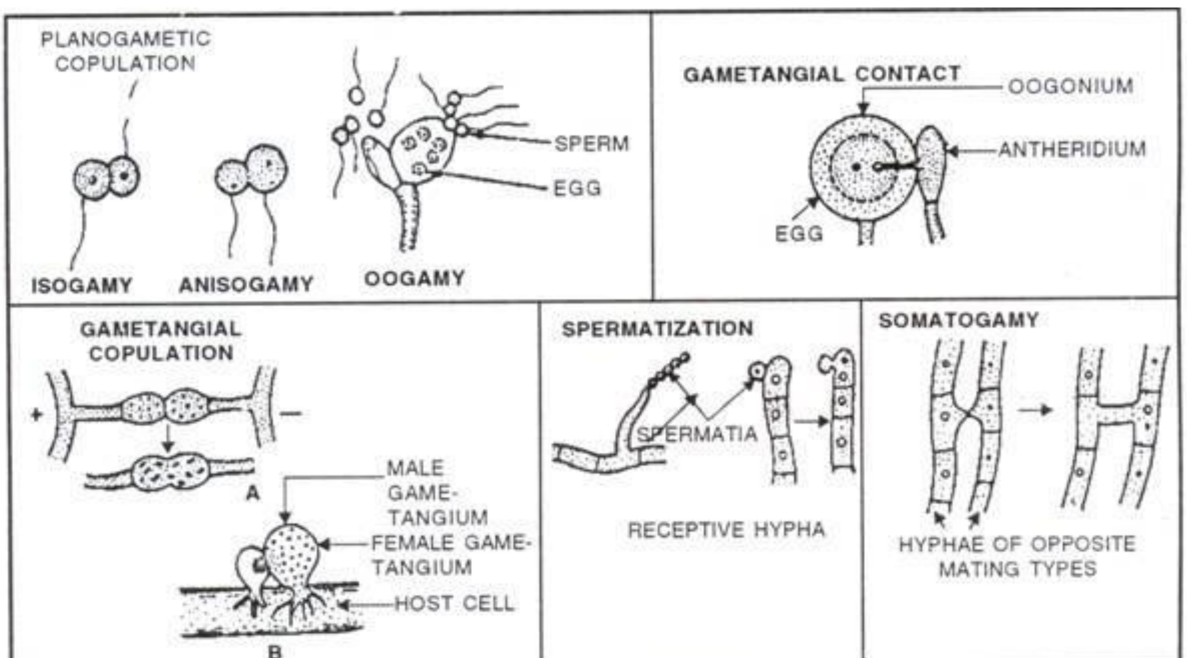

Figure 6.6 Different types of sexual reproduction in fungi.

Heterothallism, Heterokaryosis and Parasexuality

Heterothallism in Fungi

F. Blakeslee, an American Geneticist, in 1904 made an important observation with *Mucor,* which resulted in the discovery of Heterothallism. Blakeslee observed, that while some isolates of *Mucor* formed sporangia as well as zygospores (e.g., *M. tenuis*), some others failed to form the zygospores and reproduced only by sporangiospores.

Blakeslee coined the terms homothallism and heterothallism to explain this phenomenon. The homothallic species were those that produced zygospores independently, while heterothallic species required the presence of the opposite mating type. *M. hiemalis, M. mucedo, Rhizopus nigricans* are examples of heterothallic species. Since the two mating types were morphologically indistinguishable, Blakeslee designated them as the (+) and (-) mating types or strains.

Bipolar Heterothallism:

Fungi in this category have two mating types, each containing genetically different nuclei. The sexual compatibility is controlled by a pair of genetic factors A and a located at the same locus on different chromosomes. This is, therefore, also called as 'two allele heterothallism'.

During meiosis, the two chromosomes, containing the alleles A and a are separated in the haploid spores (germ spores, ascospores, or basidiospores). The spores give rise to two types of thalli, which must come together to bring together the two nuclei carrying the compatibility factors A and a. The two mating types are designated (+) and (-) strains.

The two allele or bipolar heterothallism is found in Mucorales (*Mucor, Rhizopus, Phycomyces*), Ascomycota *(Neurospora, Ascobolous*), Basidiomycota (*Puccinia graminis and Ustilago levis).*

Tetrapolar Heterothallism:

Fungi in this group form thalli of four mating types. This type of heterothallism is governed by two pairs of compatibility factors Aa and Bb, located at different chromosomes, which segregate independently during meiosis. If crossing over occurs between the mating type loci, four types of segregations (AB, Ab, aB, ab) are possible depending on the chromosomal arrangement.

Thus four types of spores (AB, Ab, aB and ab) are formed which give rise to four types of thalli. Only those thalli that have nuclei carrying opposite genes for both the factors can mate. The resulting zygote must have the genotype Aa, Bb.

Majority (63 per cent) of the heterothallic Basidiomycota are tetrapolar, forming four types of basidiospores.

However, if crossing over does not take place, only two types of spores (AB and ab or Ab and aB) are formed and only two types of thalli are produced. Since it is governed by two factors it is called tetrapolar. Heterothallism is a device for achieving outbreeding, which is a genetic desirability.

Heterokaryosis in Fungi

Heterokaryosis is the main source of variation in the anamorphic (imperfect) fungi, which lack sexual reproduction. The term Heterokaryosis was proposed by Hansen and Smith in 1932, who reported it for the first time in *Botrytis cinerea.*

The presence of genetically-different nuclei in an individual is called heterokaryosis, and the organism heterokaryon. Essentially, a heterokaryon possesses two sets of chromosomes, just like a diploid organism, but instead of being contained in a single nucleus, the two sets of chromosomes lie in separate nuclei, sharing the same cytoplasm.

Heterokaryons show dominance and, thus, resemble diploids in many respects. Heterokaryosis is a major factor in natural variability and sexuality. The heterokaryotic condition can arise in a fungus by three methods, viz., (1) Mutation, (2) Anastomosis i.e., fusion between genetically-different hyphae, and (3) Diplodization-fusion between haploid nuclei to form diploid nuclei.

Parasexuality in Fungi:

Until 1944, the sexual cycle was the only means of exchange of genetic material.In 1952 Pontecorvo and Roper of Glasgow observed parasexual cycle in *Aspergillus nidulans*,. In this, genetic recombination occurs in somatic cells by the mechanism of mitotic crossing over, which brings the same result as is achieved by the meiotic crossing over.

The parasexual cycle involves the following steps:

1. Formation of heterokaryotic mycelium.

2. Nuclear fusions and multiplication of the diploid nuclei.

3. Mitotic crossing over during division of the diploid cells.

4. Sorting out of the diploid strains.

5. Haplodization.

1. Formation of Heterokaryotic Mycelium:

The presence of genetically-different nuclei in an individual is called heterokaryosis. Essentially, a heterokaryon possesses two sets of chromosomes, just like a diploid organism, but instead of being contained in a single nucleus, the two sets of chromosomes lie in separate nuclei, sharing the same cytoplasm.

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2. Nuclear Fusions and Multiplication of the Diploid Nuclei:

Nuclear fusion in somatic heterokaryotic hyphae was first noted by Roper (1952) in *Aspergillus nidulans*. Nuclear fusion may occur between genetically similar and dissimilar nuclei, resulting in the formation of homozygous and heterozygous diploid nuclei, respectively. Diploid heterozygous nuclei are formed very rarely . In such hyphae, five types of nuclei are present- 2 types of haploid nuclei, their two types of homozygous diploids, and the one type of heterozygous diploids.

3. Mitotic Crossing Over:

Crossing over is a phenomenon which occurs during meiosis and gives rise to new linkage of genes, gene recombination. However, mitotic crossing over was discovered in 1936 by Stern in Drosophila. A similar mitotic crossing over occurs during the multiplication of the diploid heterozygous nuclei, though at a low frequency of 10-2 per nuclear division.

However, in some other fungi e.g., *Penicillium chrysogenum and Aspergillus niger*, the frequency of mitotic crossing over is as high as during meiosis in sexual reproduction. (Both species lack sexual reproduction.) Mitotic crossing over is the most important, or 'key' event in the parasexual cycle, as it is during this step that genetic recombination occurs.

4. Sorting Out of Diploid Strains:

The segregation of the diploid strains occurs when uninucleate diploid conidia are formed. The colonies that are formed by diploid conidia are recognized by various methods, e.g., higher DNA content and bigger (1.3 times) size of the conidia and certain phenotypic characters of the colony.

5. Haplodization:

The diploid colonies show appearance of sectors on the Petri plate, which produce haploid conidia. This indicates that some diploid nuclei must have undergone haplodization, forming haploid nuclei, which later get sorted out in haploid conidia. Some of these haploids are genetically different from the original haploid parental nuclei. This is because of the recombination that occurred during the mitotic crossing over.

Haplodization occurs at a constant frequency of 10-3 per nuclear division. The haplodization occurs not by a reduction division (meiosis), but by aneuploidy, a phenomenon in which chromosomes are lost during mitotic divisions. It happens in the following manner. During mitosis of the diploid nucleus, the chromatids fail to separate (non-disjunction) in the anaphase stage.

One daughter nucleus gets one chromosome more (2n + 1), while the other gets one chromosome less (2n – 1) than the normal 2 sets of chromosomes (2n). Both the daughter nuclei are called aneuploidy. The deficient aneuploid nucleus (2n – 1) may lose more chromosomes in the successive mitotic division and finally reduce to haploid state (n). Mitotic crossing over and haplodization also occur with the diploid homozygous nuclei, but since the two nuclei are similar, crossing-over products or the haploid nuclei formed by haplodization, are genetically no different from the haploid parent nuclei.

The parasexual cycle, thus, like the sexual cycle, involves plasmogamy, karyogamy and haplodization, but not at a specified time or place.

Types of fungal spores and mode of dispersal

Fungi commonly produce spores, as a result of sexual, or asexual, reproduction. Spores are usually haploid and grow into mature haploid individuals through mitotic division of cells (Urediniospores and Teliospores among rusts are dikaryotic). Dikaryotic cells result from the fusion of two haploid gamete cells. Among sporogenic dikaryotic cells, karyogamy (the fusion of the two haploid nuclei) occurs to produce a diploid cell. Diploid cells undergo meiosis to produce haploid spores.

Classification of spores

Fungi

In fungi, spores are often classified by the structure in which meiosis and spore production occurs. Since fungi are often classified according to their spore-producing structures, these spores are often characteristic of a particular taxon of the fungi.

- Sporangiospores: spores produced by a sporangium in many fungi such as zygomycetes.
- Zygospores: spores produced by a zygosporangium, characteristic of zygomycetes.
- Ascospores: spores produced by an ascus, characteristic of ascomycetes.
- Basidiospores: spores produced by a basidium, characteristic of basidiomycetes.
- Aeciospores: spores produced by an aecium in some fungi such as rusts or smuts.
- Urediniospores: spores produced by a uredinium in some fungi such as rusts or smuts.
- Teliospores: spores produced by a telium in some fungi such as rusts or smuts.
- Oospores: spores produced by an oogonium, characteristic of oomycetes.

By function

- Chlamydospores: thick-walled resting spores of fungi produced to survive unfavorable conditions.
- Parasitic fungal spores may be classified into internal spores, which germinate within the host, and external spores, also called environmental spores, released by the host to infest other hosts.

By origin during life cycle

- Mitospores (or **conidia**, **conidiospores**): spores produced by mitosis; they are characteristic of Ascomycetes. Fungi in which only mitospores are found are called "mitosporic fungi" or "anamorphic fungi", and are previously classified under the taxon Deuteromycota .

By mobility

Spores can be differentiated by whether they can move or not.

- Ballistospores: spores that are forcibly discharged or ejected from the fungal fruiting body as the result of an internal force, such as buildup of pressure. Most basidiospores are also ballistospores, and another notable example is spores of the genus Pilobolus.
- Statismospores: spores that are discharged from the fungal fruiting body as the result of an external force, such as raindrops or a passing animal. Examples are puffballs.

Spore dispersal

In fungi, both asexual and sexual spores or sporangiospores of many fungal species are actively dispersed by forcible ejection from their reproductive structures. This ejection ensures exit of the spores from the reproductive structures as well as travelling through the air over long distances. Many fungi thereby possess specialized mechanical and physiological mechanisms as well as spore-surface structures, such as hydrophobins, for spore ejection. These mechanisms include, for example, forcible discharge of ascospores enabled by the structure of the ascus and accumulation of osmolytes in the fluids of the ascus that lead to explosive discharge of the ascospores into the air.

Classification of Fungi

Classification of Fungi by Ainsworth G. C. (1966, 71, 73):

Ainsworth G. C. (1966, 71, 73) proposed a more natural system of classification of fungi. This classification is based on morphology, especially of reproductive structure. He includes fungi along with slime molds under the kingdom Mycota.

Based on the presence or absence of Plasmodium and pseudoplasmodium; the kingdom Mycota is further divided into two divisions:

Myxomycota i.e., slime molds and Eumycota or true fungi. Divisions are subsequently divided into subdivision, class, subclass, order, family and then to genus. According to his classification, division ends in mycota, subdivision in mycotina, class in mycetes, subclass in mycetidae order in ales and family in aceae.

A schematic outline of Ainsworth's (1973) classification is given:

Kingdom: Mycota

Important features:

i. Free-living, parasitic or mutualistic symbionts, devoid of chlorophyll.
ii. Cell wall composition is very variable, majority contain chitin and glucan.
iii. Reserve food materials are oil, mannitol and glycogen.
iv. Except some unicellular members, majority are filamentous.

A. Division. Myxomycota:

Wall-less organisms possess either a Plasmodium (a mass of naked multinucleate protoplasm having amoeboid movement) or a pseudoplasmodium (an aggregation of separate amoeboid cells). Both are of slimy consistency, hence slime molds.

1. Class. Acrasiomycetes (cellular slime molds)
2. Class. Hydromyxomycetes (net slime molds)
3. Class. Myxomycetes (true slime molds)
4. Class. Plasmodiophoromycetes (endo- parasitic slime molds).

B. Division Eumycota (True fungi, all with walls):

a. Subdivision Mastigomycotina (motile cells – zoospores present, perfect state spore-oospore).

1. Class. Chitridiomycetes (unicellular, zoospore with single whiplash flagellum).

2. Class. Hyphochytridiomycetes (unicellular, zoospore with single tinsel flagellum).
3. Class. Oomycetes (aseptate mycelium, zoospores with two flagella).

b. Subdivision. Zygomycotina (mycelium aseptate, perfect state spore-zygospore).

1. Class. Zygomycetes (mycelium immersed in the host tissue).
2. Class. Trichomycetes (mycelium not immersed in the host tissue).

c. Subdivision. Ascomycotina (yeasts or septate mycelium, perfect state spore- ascospores formed in ascus, usually within ascocarp).

1. Class. Hemiascomycetes (no ascocarp, asci naked).
2. Class. Loculoascomycetes (fruit body an ascostroma, asci bitunicate i.e., 2-walled).
3. Class. Plectomycetes (fruit body cleistothecium, asci unitunicate i.e., 1-walled).
4. Class. Laboulbeniomycetes (fruit body perithecium, asci unitunicate, exoparasite of arthopods).
5. Class. Pyrenomycetes (fruit body perithecium, asci unitunicate, not parasitic on arthopods.
6. Class. Discomycetes (fruit body apothecium, asci unitunicate).

d. Subdivision. Basidiomycotina (yeast or septate mycelium, perfect state spore – basidiospore formed on a basidium).

1. Class. Teliomycetes. Basidiocarp lacking, teliospores grouped in sori or scattered within the host tissue, parasitic on vascular plant.
2. Class. Hymenomycetes. Basidio- carp present. Hymenium is completely or partly exposed at maturity. Basidiospore ballistospores.
3. Class. Casteromycetes. Basidiocarp present. Hymenium enclosed in basidiocarp. Basidiospore not ballistospores.

(e) Subdivision. Deuteromycotina or Fungi imperfecti. Yeast or septate mycelium. Perfect state unknown.

1. Class. Blastomycetes. Budding (Yeast or Yeast like) cells with or without pseudomycelium. True mycelium lacking or not well-developed.
2. Class. Hyphomycetes. Mycelia sterile or bearing asexual spore directly or on conidiophore, in various aggregation.
3. Class. Coelomycetes. Mycelial; asexual spore formed in pycnidium or acervulus.

Schematic representation of the outline with figure, the classification of G.C. Ainsworth (1973) is given:

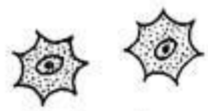
Schematic outline of the classification of G. C. Ainsworth (1973):

Kingdom — MYCOTA

Plasmodium or pseudoplasmodium present

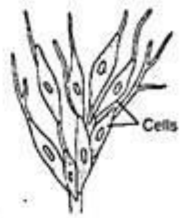
Division. MYXOMYCOTA

- Assimilative phase free-living amoebae which unite as pseudomycelium before reproduction



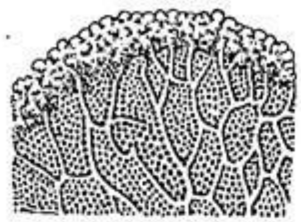
Ceratiomyxella tahitiensis
Class : Acrasiomycetes
e.g. *Acrasis*, *Guttulina*

- Assimilative phase a net-plasmodium



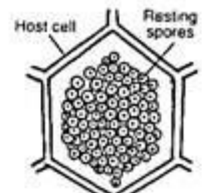
Net plasmodium of *Labyrinthula* sp.
Class : Hydromyxomycetes
e.g. *Zostera*, *Labyrinthula*

- Assimilative phase is not a net-plasmodium, saprophytic



Plasmodium of *Physarum*
Class : Myxomycetes
e.g. *Stemonites*. *Physarum*

- Assimilative phase is not a net-plasmodium, parasitic

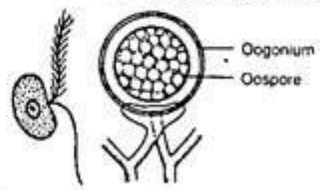


Plasmodiophora brassicae
Class : Plasmodiophoromycetes
e.g. *Plasmodiophora brassicae*

Plasmodium or pseudoplasmodium absent. Assimilative phase typically filamentous

Division. EUMYCOTA

- Motile cells (zoospores) present
Perfect state spores typically Oospores



Zoospore and Oospore of *Phytophthora*
Sub-division : MASTIGOMYCOTINA
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- Motile cells absent
↓

Contd. →

Contd.

Motile cells absent

Sub-division : MASTIGOMYCOTINA

Zoospore uniflagellate (whiplash type)

Synchytrium
Class : Chitridiomycetes
e.g. *Olpidium, Synchytrium*

Zoospore uniflagellate (tinsel type)

Rhizidiomyces
Class : Hyphochytridiomycetes
e.g. *Rhizidiomyces, Rhizidiomycopsis*

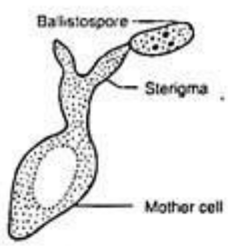
Zoospore biflagellate (one whiplash and other tinsel type)

Phytophthora
Class : Oomycetes
e.g. *Pythium, Phytophthora*

Perfect state absent
Sub-division : DEUTEROMYCOTINA

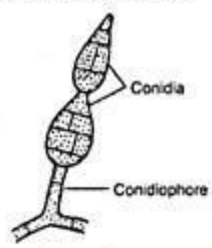
Perfect state present

True mycelium lacking or not well developed



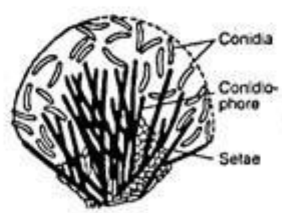
Sporobolomyces roseus
Class : Blastomycetes
e.g. *Sporobolomyces, Bullera*

True mycelium may be sterile or bearing spores directly or on sporophores



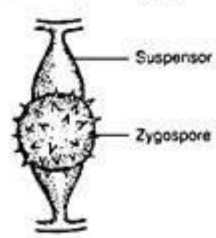
Alternaria
Class : Hyphomycetes
e.g. *Botrytis, Rhizoctonia*

True mycelium aggregated to form pycnidium or acervulus produces spores inside



Acervulus of *Colletotrichum*
Class : Coelomycetes
e.g. *Colletotrichum, Pestalotia*

Perfect state spore-Zygospore



Single zygospore of *Mucor*
Subdivision :
ZYGOMYCOTINA
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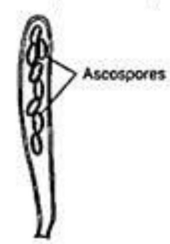
Perfect state spore-Ascospore



An ascus of *Ascobolus*
Subdivision :
ASCOMYCOTINA
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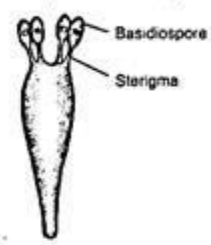
Perfect state spore-Basidiospore



Single basidium of *Agaricus*
Subdivision :
BASIDIOMYCOTINA
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Contd. →

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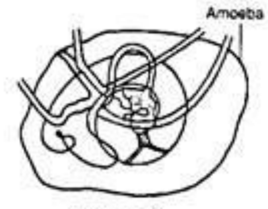
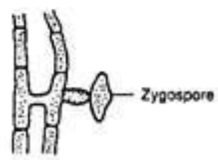
Subdivision : ZYGOMYCOTINA

- Saprobic or if parasitic or predaceous having mycelium immersed in host tissue



Thallus of *Cochlonema verrucosum*
Class : Zygomycetes
e.g. *Rhizopus, Cochlonema*

- Generally associated with arthopods and mycelium not immersed in host tissue



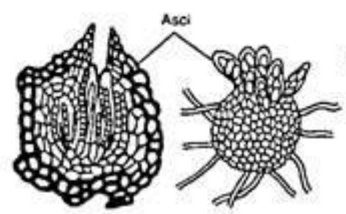
Harpella
Class : Trichomycetes
e.g. *Asellaria, Enterobotryus*

Subdivision : ASCOMYCOTINA

- Ascocarp absent

Naked asci of *Taphrina* on host surface
Class : Hemiascomycetes
e.g. *Protomyces, Taphrina*

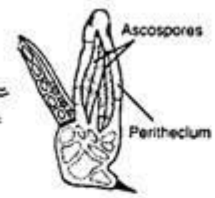
- Ascocarp an ascostroma
- Ascocarp cleistothecium



Ascostroma of *Mycosphaerella*
Class : Loculoascomycetes
e.g. *Venturea, Pleospora*

Cleistothecium of *Erysiphe*
Class : Plectomycetes
e.g. *Aspergillus, Penicillium*

- Ascocarp perithecium, ectoparasite of arthopods



Sporulating thallus of *Laboulbenia formicarum*
Class : Laboulbeniomycetes
e.g. *Laboulbenia, Stigmatomyces*

- Ascocarp perithecium, not ectoparasite of arthopods

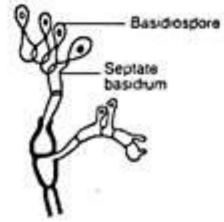
Perithecium of *Neurospora dodgei*
Class : Pyrenomycetes
e.g. *Claviceps, Xylaria*

- Ascocarp apothecium

Apothecia of *Ascobolus scatigenus*
Class : Discomycetes
e.g. *Peziza, Ascobolus*

Subdivision : BASIDIOMYCOTINA

- Basidiocarp lacking

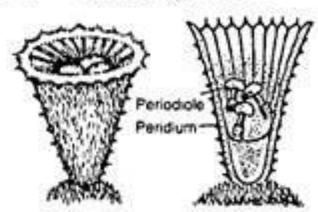


Germinated teleutospore of *Puccinia graminis*
Class : Teliomycetes
e.g. *Puccinia, Ustilago*

- Basidiocarp present and typically gymnocarpous or semiangiocarpous

Basidiocarp of *Agaricus*
Class : Hymenomycetes
e.g. *Agaricus, Polyporus*

- Basidiocarp present and typically angiocarpous



A basidiocarp of *Cyathus* and V.S. of basidiocarp of *Cyathus*
Class : Gasteromycetes
e.g. *Cyathus, Geastrum*

Phylogeny of Fungi

Molecular phylogenetic analyses that became possible during the 1990s have greatly contributed to the understanding of fungal origins and evolution. At first, these analyses generated evolutionary trees by comparing a single gene sequence, usually the small subunit ribosomal RNA gene (*SSU rRNA*). Since then, information from several protein-coding genes has helped correct discrepancies, and phylogenetic trees of fungi are currently built using a wide variety of data largely, but not entirely, molecular in nature.

Until the latter half of the 20th century, fungi were classified in the plant kingdom (subkingdom Cryptogamia) and were separated into four classes: Phycomycetes, Ascomycetes, Basidiomycetes, and Deuteromycetes. These traditional groups of fungi were largely defined by the morphology of sexual organs, by the presence or absence of hyphal cross walls (septa), and by the degree of chromosome repetition (ploidy) in the nuclei of vegetative mycelia. The slime molds, all grouped in the subdivision Myxomycotina, were also included in Division Fungi.

In the middle of the 20th century the three major kingdoms of multicellular eukaryotes, kingdom Plantae, kingdom Animalia, and kingdom Fungi, were recognized as being absolutely distinct. The crucial character difference between kingdoms is the mode of nutrition: animals (whether single-celled or multicellular) engulf food; plants photosynthesize; and fungi excrete digestive enzymes and absorb externally digested nutrients. There are other notable differences between the kingdoms. For example, whereas animal cell membranes contain cholesterol, fungal cell membranes contain ergosterol and certain other polymers. In addition, whereas plant cell walls contain cellulose (a glucose polymer), fungal cell walls contain chitin (a glucosamine polymer). One exception to this rule is a group of fairly ubiquitous microscopic fungi, members of which average about 3 to 5 μm (1 μm is about 0.000039 inch) in length, have cell walls lacking chitin, and possess a flagellum. Phylogenetic analyses of ribosomal RNA in this clade suggest that it is an ancient fungal group.

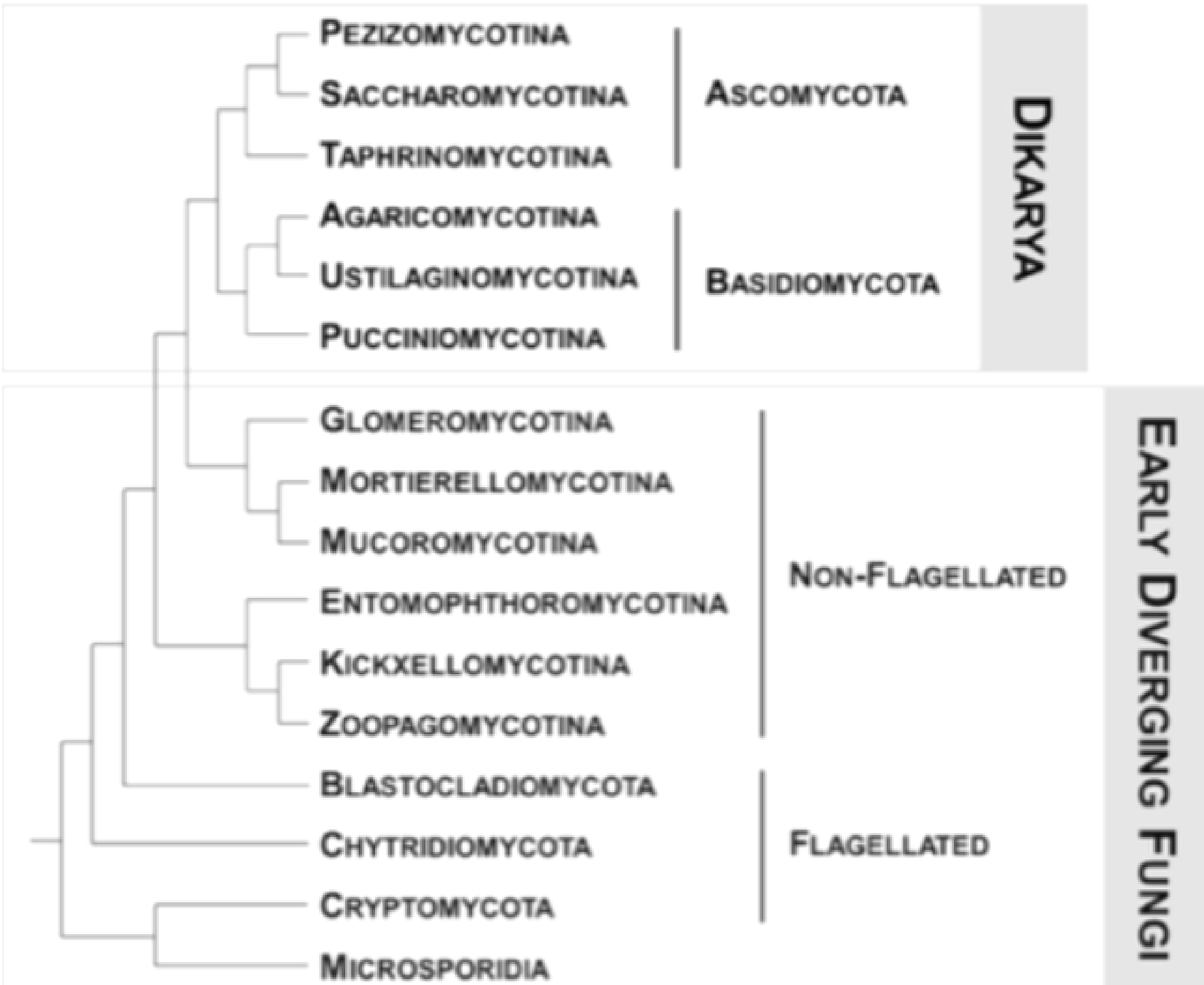
Genomic surveys show that plant genomes lack gene sequences that are crucial in animal development, animal genomes lack gene sequences that are crucial in plant development, and fungal genomes have none of the sequences that are important in controlling multicellular development in animals or plants. Such fundamental genetic differences imply that animals, plants, and fungi are very different cellular organisms. Molecular analyses indicate that plants, animals, and fungi diverged from one another almost one billion years ago.

Although fungi are not plants, formal recognition of fungal nomenclature is governed by the International Code of Botanical Nomenclature. In addition, the taxon “phylum” is used in fungal nomenclature, having been adopted from animal taxonomy. The phylogenetic classification of fungi is designed to group fungi on the basis of their ancestral relationships, also known as their phylogeny. The genes possessed by organisms in the present day have come to them through the lineage of their ancestors.

Kingdom Fungi, one of the oldest and largest groups of living organisms, is a monophyletic group, meaning that all modern fungi can be traced back to a single ancestral organism. This ancestral organism diverged from a common ancestor with the animals about 800 million to 900 million years ago. Today many organisms, particularly among the phycomycetes and slime molds, are no longer considered to be true fungi, even though mycologists might study them. This applies to the water molds (e.g., the plant pathogen *Phytophthora*, the cause of potato late blight), all of which have been reclassified within the kingdom Chromista (phylum Oomycota). Similarly, the Amoebidales, which are parasitic or commensal on living arthropods and were previously thought to be fungi, are considered to be protozoan animals. None of the slime molds are placed in kingdom Fungi, and their relationship to other organisms, especially animals, remains unclear.

Kingdom Fungi has gained several new members on the basis of molecular phylogenetic analysis, notably *Pneumocystis*, the Microsporidia, and *Hyaloraphidium*. *Pneumocystis jirovecii* causes pneumonia in mammals, including humans with weakened immune systems; pneumocystis pneumonia (PCP) is the most common opportunistic infection in people with human immunodeficiency virus (HIV) and has been a major cause of death in people with AIDS. *Pneumocystis* was initially described as a trypanosome, but evidence from sequence analyses of several genes places it in the fungal subphylum Taphrinomycotina in the phylum Ascomycota. The Microsporidia were thought to be a unique phylum of protozoa for many years; however, molecular studies have shown that these organisms are fungi. *Hyaloraphidium curvatum* was previously classified as a colourless green alga; however, it has since been recognized as a fungus on the basis of molecular sequence data, which show it to be a member of the order Monoblepharidales in the phylum Chytridiomycota.

Fungal phylogeny



General account of Mastigomycotina and Zygomycotina

MASTIGOMYCOTINA

- They are commonly known as zoosporic fungi.
- They are mostly aquatic while another group are primarily terrestrial, although the organisms still form motile zoospores when open water is available.
- Three types of zoospores are common in this group. These are: (a) Laterally biflagellate, (b) Posteriorly uniflagellate, and (c) Anteriorly uniflagellate type having "9 + 2" arrangement of component fibrils.
- Most of them are filamentous and have coenocytic mycelium. However, unicellular form are present, and some genera show the pseudosepta (false cross wall) formation. Rhizoids are present in some of unicellular forms.
- Live either as saprophytes or parasites. Due to presence of haustoria in a majority of Mastigomycotina, the mode of nutrition is typically absorptive.
- Sexual reproduction takes place by gametic copulation, gametangial copulation and gametangial contact. Oospores formation are common in almost all Mastigomycotina.

CLASSIFICATION OF MASTIGOMYCOTINA

- **Ainsworth (1973) classified the subdivision Mastigomycotina into three classes:**
- **Chytridiomycetes:** They produces posteriorly uniflagellate zoospores Chytridiomycetous fungi occur as saprobes on plants and animal remains in water while other members occur as parasites on algae and aquatic animals.
- **Hyphochytriomycetes:** Zoospores are anteriorly uniflagellate. The hyphochytridiomycetes are those aquatic fungi whose thallus is holocarpic or eucarpic, monocentric or polycentric and their vegetative system is rhizoidal or hypha-like with intercalary swellings.
- **Oomycetes:** The Oomycetes contain 74 genera and 580 species, which are mostly aquatic, though some are terrestrial and live as parasites or saprophytes. Includes classic "water molds" in the Order Saprolegniales and the "downy mildews" in the Order Peronosporales.

Class: Chitridiomycetes

Main distinguishing characteristics:

- The vegetative body is unicellular or chain of cells attached with the substratum by rhizoids.
- Cell wall is mainly made up of chitin and glucans.
- The plant body is normally haploid, except*Allomyces*.

- Asexual reproduction takes place by zoospores produced in zoosporangium; zoospores are uniflagellate, flagellum whiplash type and posteriorly placed.
- Sexual reproduction takes place by piano- gametes developed in gametangia.
- The fused gametes form zygote. After resting period, it undergoes meiosis and forms new haploid thallus.
- Most of the members of the class is aquatic.
- Some of them are terrestrial and parasitic.
- Important parasitic members are *Synchytrium endobioticum* causes wart disease of potato; *Olpidium brassicae*, in roots of Crucifers; *Urophlyctis alfalfae* causes crown wart of alfalfa (Medicago); and *Physoderma maydis* causes brown spot of maize etc.
- *Coelomomyces anophelescia* is an endoparasite on mosquito larvae and can be utilized for the biological control of Anopheles mosquito.

Classification:

On the basis of vegetative and reproductive structures, the class Chytridiomycetes is divided into following orders:

- **Order Chytridiales:** It is by far the largest order and includes the most primitive members of the class.
- The somatic phase is microscopic, holocarpic or eucarpic, single celled structure which in some
- species is drawn out at a point into fine branching extensions constituting the rhizomycelium.
- True mycelium is lacking. The zoospore has a refractive oil globule but may lack of nuclear cap.
- It swims with a hopping movement or creeps over solid substratum like an amoeba.
- **Order Harpochytridiales:** It is a small order represented by the two genera *Harpochytrium* and *Oedogoniomycei.* They are placed in the family Harpochytriaceae.
- **Order Blastochytridiales:** The vegetative body is a typical mycelium. Sexual reproduction is or aniso-planogamous. They are paced in the family Hypochytriaceae.
- **OrderMonoblepharidales:** The vegetative body is a typical mycelium as in the Blastochytridiales.
- Sexual reproduction is heterogamous and takes place by the fusion of a motile male gamete and a non motile female gamete. Resistant sporangia are lacking.
- The zoospores are similar to those of the Blastochytridiales.

Class: Hypochitridiomycetes

- They are distinguished by an anterior tinsel flagellum on their zoospores. Also they have a rhizoidal or hypha-like vegetative system (hence the prefix "Hypho-").

Classification:

- This group may be put alternatively at the phylum, class, subclass or order level, being referred to as Hyphochytriomycota, Hyphochytriomycetes (or Hyphochytrea), Hyphochytriomycetidae (or Hyphochytridae) and Hyphochytriales, respectively.

- The variants Hyphochytri*di*omycota and Hyphochytri*di*omycetes are also sometimes used, presumably by analogy to the Chytridiomycetes, or due to the perpetuation of a typographical error. However, the stem is Hyphochytri- (from *Hyphochytrium*) and not Hyphochytridi- (from *Chytridium*). The class include

- Order Hyphochytriales

Family Hyphochytriaceae

Genus Canteriomyces Genus Cystochytrium Genus Hyphochytrium

Family Rhizidiomycetaceae

Genus *Latrostium*

Genus *Reessia*

Genus *Rhizidiomyces*

Class: Oomycetes

- Vegetative body is filamentous and coenocytic except the unicellular Lagenidiales.
- Members of this class are either holocarpic or eucarpic. Majority of species are eucarpic.
- **Holocarpic** - Entire thallus converted into reproductive structure.
- **Eucarpic** - Reproductive organs arise from only a portion of the thallus.
- Cell wall contains cellulose and glucans. Chitin is absent.
- Asexual reproduction is by biflagellate heterokont (different) and anisokont (unequal) zoospores that are produced in zoosporangia.
- Zoosporangia- Modified hyphae that are usually terminal and delimited by a septum
- Zoospores are diploid formed by mitosis.
- Anteriorly directed flagellum is tinsel type and posteriorly directed is whiplash type. Depending on genera single type-monomorphic or two types of zoospores are formed-dimorphic. Two types of zoospores are formed in the life cycle are:
- **Primary zoospores** - First formed and the flagella are located anteriorly. Primary zoospore is
- released from the zoosporangium, encyst and germinates to form the secondary zoospore.
- **Secondary zoospores** - The secondary zoospore which is reniform or bean-shaped and laterally flagellated.

- Zooporangium and zoospores are the major dispersal agents for most species.
- **Sexual reproduction**:- Sexual reproduction is heterogamous (oogamous) by oogonia (female)
- and antheridia (male).
- Female gamete (oosphere) produced by an oogonium. Depending on taxon, there may be one to many oospheres per oogonium.
- Male gamete is produced by antheridium and transferred to the oogonium by gametangial contact and migration of male nuclei into oogonia and fertilize oospheres.
- Homothallic–self- fertileor Heterothallic–opposite mating types required for sexual
    - reproduction.
- A swimming sperm is absent in the Oomycetes. This type of sexual reproduction is referred to as gametangial copulation.
- In antheridia and oogonia meiosis take place. The eggs and sperms are products of meiosis and the only parts of the life cycle that are haploid.
- Diploid zygote develops into thick-walled resistant oospore that germinates and give rise to vegatative diploid hyphae that reproduce asexually by production of zoospores.
- The vegetative body is diploid and the life cycle is diplontic.

Classification:

- Class Oomycetes is divided into four orders. Lagenidiales (Salilagenidiales), Leptomitales Saproleginales and Peronosporales
- Peronosporales: This order has some of the most well known pathogens (fungi cause diseases) cause diseases to many a crop plants. Peronosporales:- divided into three families :
    - Family Pythiaceae, Genus: *Pithium*, *Phytophthora*
    - Family Peronosporaceae, Genus: *Plasmopara*
    - Family Albuginaceae, Genus: *Albugo*.
- Peronosporales differs from the Saprolegniales in producing only secondary zoospores in a zoosporangium.
- That is differentiated from hyphae (eucarpic) and one oosphere (egg) per oogonium.
- Zoosporangia often deciduous and zoospores often formed in vesicle.
- They are aquatic, amphibious, terrestrial and some of the most destructive plant pathogens.
- The most economically important group of Oomycetes is the Peronosporales that contain the late blight of potato fungus *Phytophthora infestans* and relatives such as *Peronospora*, *Bremia*, *Plasmopara* and others that cause “downy mildews”, the “damping off” fungi, *Pythium* spp., and the white rust fungi, *Albugo* spp.

Some important parasitic members of this group are:

- *Pythium*: Different species of *Pythium* cause foot rot, fruit rot, rhizome rot and damping off.
- *Phytophthora:* Phytophthora cause stem and leaf blight, foot rot, leaf rot, corm rot, fruit rot etc.
- *Plasmopara: P. viticola* causes downy mildew of grapevine.
- *Albugo*. Different species of *Albugo* cause white rust disease of different hosts like crucifers (cabbage, Brassica, radish, rurnip etc.), spinach, sweet potato, morning glories etc. The *A. Candida* is very common causing white rust of crucifers.
- *Saprolegnia*: *S. parasitica*, a parasite on fish, is an aquatic member.