II. Fungi

Fungi were previously classified as part of the plant kingdom due to the presence of a cell wall and several similarities between their reproductive cycles and those of algae. However, in 1969, Whittaker classified them into a separate kingdom, Mycota, based on several distinct characteristics, such as the absence of chlorophyll and starch.

Fungi, also known as mycetes or Mycota, form their own kingdom. They are eukaryotic organisms related to plants but differ from them, particularly in their non-photosynthetic mode of nutrition.

The fungal group consists of approximately 120,000 species. These organisms require a significant amount of water to complete their biological cycle and therefore only thrive in very humid terrestrial environments. Unlike other plant groups, they never possess chlorophyll or plastids and are heterotrophic for carbon. The first fungi are believed to have appeared during the Precambrian era, around 600 million years ago.

Fungi exhibit a wide variety of life forms. The simplest are unicellular, but most are multicellular. They feed on organic matter from their surroundings by secreting enzymes that "digest" various organic compounds, breaking them down into small soluble molecules. These molecules then diffuse through their cell walls.

1 - Mode of life

Fungi are heterotrophic and must find ways to obtain the carbon necessary for their survival. They exploit their immediate environment, absorbing organic matter in three different ways:

- **Saprophytic fungi:** These fungi feed on dead or decaying organic matter, such as dead leaves, plant debris, animal remains, or excrement.
- **Parasitic fungi:** These fungi feed on living organic matter, including plants, animals (including humans), or even other fungi.
- **Symbiotic fungi:** Some fungi prefer symbiosis or mutualism, forming associations with autotrophic plants, where both organisms benefit from the relationship. Symbiosis sometimes results in the creation of new entities, such as lichens or mycorrhizae.

A **lichen** is neither a moss, a plant, nor a single organism but rather a symbiotic association between a fungus and an alga. In **mycorrhizae**, the fungus provides minerals extracted from the soil, while the plant supplies organic compounds that it synthesizes. More than 95% of all vascular plants have mycorrhizae.

The cells of fungi release enzymes that break down complex substances such as proteins, fats, and sugars into simpler compounds. These simpler substances, along with water and mineral salts, then enter the fungal cells.

2 - Morphology

Fungi are **thallophytes**, meaning they lack leaves, stems, and roots. Their vegetative body, or thallus, consists of elongated cells that may be partitioned and compartmentalized. These structures are called **hyphae**. Each compartment represents a cell containing one or more nuclei.

When there are no partitions separating the cells, the structure is referred to as a **siphon (coenocyte)** or **non-septate hyphae**. Hyphae group together to form a network of interwoven filaments known as **mycelium**.

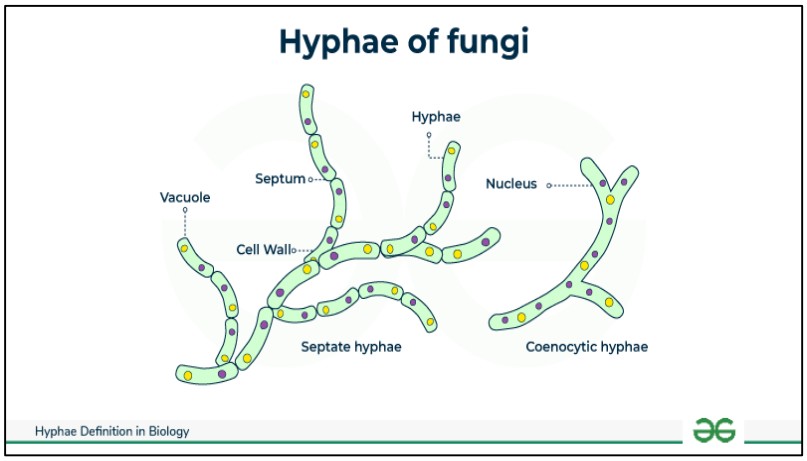


Figure : Septate and non-septate hyphae

3 - Cytology

- The cytoplasm contains mitochondria, an endoplasmic reticulum with ribosomes, protein vesicles, microtubules, glycogen, and lipid granules.
- The cytoplasmic membrane is surrounded by a complex cell wall composed of carbohydrates, simple polysaccharides (mannans, glucans, cellulose), amino polysaccharides (chitin, chitosan), sterols (mainly ergosterol), and polyols.
- Black fungi contain melanin in their cell walls, sometimes in significant concentrations.

4 - Reproduction

Fungi reproduce using three methods: Fragmentation, Budding and Spores.

a- Fragmentation

This is the simplest form of asexual reproduction. A small fragment separates from the main fungal mass and develops into a new individual. More specifically, pieces of hyphae break off and form new mycelia.

b- Budding

Unicellular yeasts reproduce asexually through budding. They duplicate their nucleus, and a small bud begins to form on the cell wall. This bud, containing the new nucleus, continues to grow until it becomes a fully independent cell.

c- Spores

Fungi produce spores through sexual or asexual reproduction, which are dispersed by the wind.

Spores are formed within specialized compartments of the hyphae, known as **asci , basidia , or zygosporangia**

Spore germination and mycelial development:

When a spore germinates, it gives rise to a haploid mycelial filament (n chromosomes) called **primary mycelium**. However, this primary mycelium remains sterile unless it encounters another primary filament of the opposite mating type.

This fusion results in a **secondary mycelium**, which is fertile and contains binucleate cells (2 chromosomes)**.** The mycelial filaments branch out and spread in all directions. Under ideal conditions, the mycelium forms a disc-like structure on the surface of the substrate.

When the mycelium has stored enough nutrients and the environmental conditions are favorable, a primordium develops. This primordium grows into a sporophore; the visible part of the fungus, formed by the fusion of mycelial filaments. The sporophore eventually produces new spores, continuing the fungal life cycle.

5 - Taxonomy

The **"true fungi"** (Eumycetes) are classified into four phyla:

- **Deuteromycota** (*Deuteromycetes* or *imperfect fungi*)
- **Zygomycota** (*Zygomycetes*)
- **Ascomycota** (*Ascomycetes*)
- **Basidiomycota** (*Basidiomycetes*)

The **Oomycetes** group has been excluded from the fungal kingdom because it is more closely related to algae.

The **Chytridiomycetes** are a poorly understood group of fungi.

1 - <u>Deuteromycetes (Imperfect Fungi)</u>

Deuteromycetes, or **"imperfect fungi"**, belong to the group of fungi with septate hyphae that reproduce asexually (vegetatively). Their method of sexual reproduction, if it exists, is still unknown.

Since their classification is based on the absence of a known sexual phase, Deuteromycetes form an artificial group rather than a true fungal class. This category was created to classify fungi with septate hyphae that cannot be placed elsewhere due to the lack of observed sexual reproduction.

Deuteromycetes include many species of medical importance. While their classification is artificial, it is still useful for identifying fungi that do not exhibit sexual reproduction. This grouping is based on morphological characteristics rather than true classes, orders, or families. Some researchers use terms like morpho-genus or morpho-species to describe them.

Main groups of Deuteromycetes (Based on Spore-Producing Structures)

- **Agonomycetes** – Unicellular fungi like **yeasts**
- **Coelomycetes** – Fungi with grouped reproductive structures
- **Hyphomycetes** – Fungi with dispersed reproductive structures

2 - <u>Ascomycetes (Sac Fungi)</u>

2.1 - General Characteristics

Ascomycetes are characterized by spores formed inside specialized sac-like cells called asci. These spores are known as ascospores.

With over 48,000 described species, Ascomycetes have septate mycelium. Many of them, like Penicillium (often green molds), reproduce asexually (in certain *Penicillium* species, sexual reproduction has been observed), meaning they do not produce asci.

Yeasts are a unique type of Ascomycetes that lack mycelium and consist of isolated cells that reproduce by budding. In nature, yeasts commonly grow on the skin of fruits.

Some Ascomycetes produce visible fruiting bodies (carpophores), and some are edible, such as truffles, morels, and peziza fungi.

More than half of all Ascomycetes form symbiotic relationships:

- With algae, forming lichens
- With plant roots, forming mycorrhizae

Many Ascomycete species are used in the production of antibiotics, medicines, and fermentation processes. Some, such as morels and truffles, are highly valued for their gastronomic importance. However, some Ascomycetes are dangerous parasites that infect plants, animals, and humans. They include some of the most destructive plant pathogens.

Ascomycetes produce their spores inside specialized sacs called **asci**. Once the spores mature, they are forcibly ejected from the ascus through an opening, allowing them to disperse into the environment.

2.2 - Reproduction in Ascomycetes

a- Asexual Reproduction

Ascomycetes reproduce asexually by producing **conidiospores** or **conidia**. These spores germinate to form new septate hyphae, which in turn develop conidiophores that produce more conidia, continuing the cycle.

b- Sexual Reproduction

1. Fusion of Opposite Mating Types: Two mycelia of opposite sexual types intertwine and form a gametangium called an ascogonium.
2. Exchange of Genetic Material: The ascogonium contains nuclei from both parent fungi.
3. Formation of Ascocarp: The ascogonium produces specialized hyphae, which develop into a fruiting body (ascocarp).
4. Development of Asci: The tips of certain hyphae within the ascocarp differentiate into asci. Inside each ascus, the fusion of nuclei (karyogamy) occurs, followed by meiosis and mitosis, producing eight haploid nuclei.
5. Formation of Ascospores: A cell wall forms around each nucleus, resulting in the creation of eight ascospores inside the ascus.
6. Spore Release and Germination: When mature, the ascospores are ejected from the ascus and germinate to form new haploid mycelia, completing the cycle.

2.3. Examples of Ascomycetes:

a- The Genus *Penicillium*:

Penicillium species are widespread in the environment and frequently contaminate food products. However, certain species are used in industry, such as:

- *P. roqueforti* (used in blue cheese production),
- *P. camemberti* (used in Camembert and Brie cheese),
- *P. nalgiovense* (used in the curing of dry sausages).

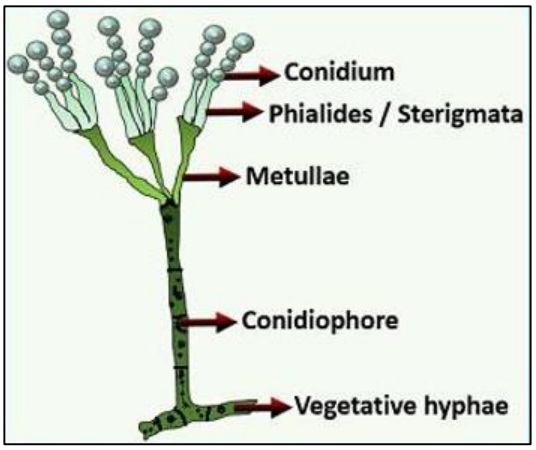


Figure : Penicillium sp

Some species also produce metabolites of medical interest. In 1928, **Alexander Fleming** discovered **penicillin** from a strain of *P. notatum*, marking a major breakthrough in medicine.

Only a few *Penicillium* species are associated with human pathology.

• Taxonomic classification:

- **Kingdom:** Fungi
- **Phylum:** Ascomycota
- **Subphylum:** Pezizomycotina
- **Class:** Eurotiomycetes
- **Subclass:** Eurotiomycetidae
- **Order:** Eurotiales
- **Family:** Trichocomaceae
- **Genus:** *Penicillium*

• Description :

Penicillium species are characterized by the presence of **erect conidiophores**, which are more or less branched and terminate in specialized structures called **phialides**.

The phialides are arranged in whorls at the tips of the conidiophores. They may be :

- Directly attached (*monoverticillate Penicillium*),
- Attached through a single row of supporting cells called metulae (*biverticillate Penicillium*),
- Attached through two successive rows of metulae (*triverticillate Penicillium*).

The **conidia** (asexual spores) are produced in large numbers by the phialides, remaining in chains and giving the conidial head a characteristic **brush-like appearance** (resembling a paintbrush or "penicillus," which inspired the genus name).

• Reproduction:

▪ Asexual reproduction:

When conditions are favorable, the conidia germinate and develop into a vegetative mycelium. This mycelium grows and forms conidiophores, which bear metulae and phialides, at the tips of which new conidia are produced in succession.

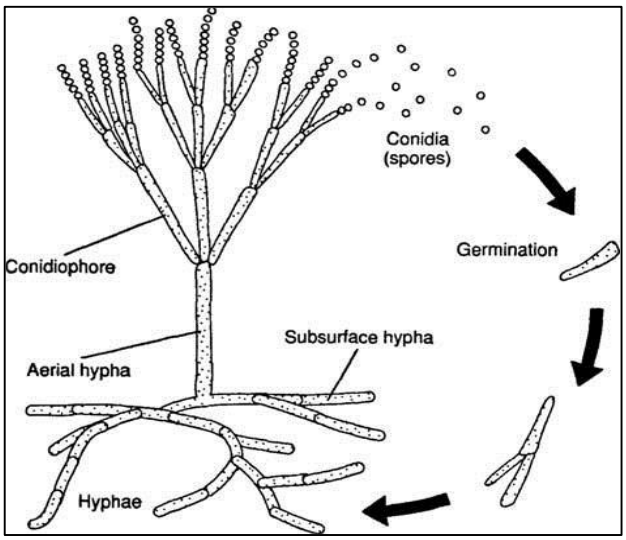


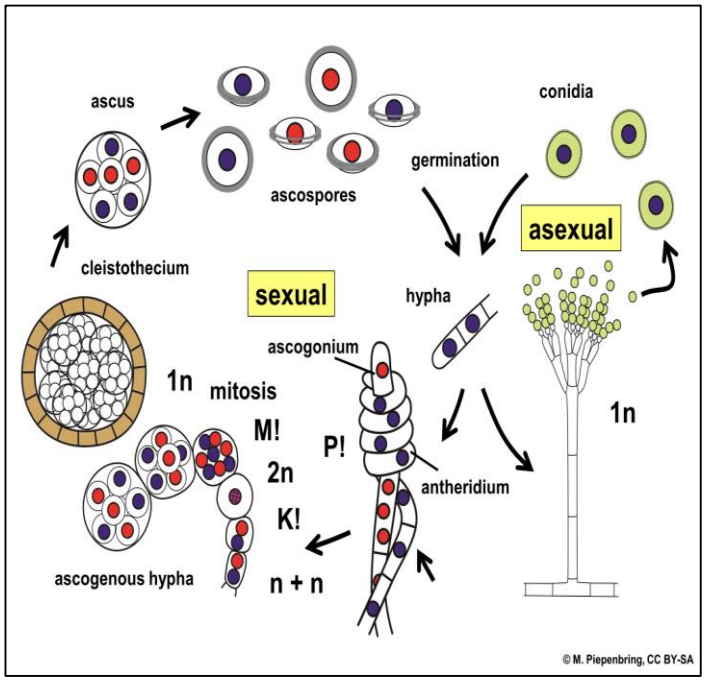
Figure : Asexual reproduction of Genus Penicillium

▪ Sexual reproduction:

Some *Penicillium* species have a sexual stage, but it was only discovered in certain species.

- The spores germinate, producing haploid septate filaments.
- These filaments branch extensively, forming the primary mycelium.
- When two primary mycelia come into contact, they can enter the sexual reproduction phase.
- On one of the two primary mycelia, a multinucleate cell differentiates and functions as the male gametangium (antheridium).
- In close proximity, the other primary mycelium differentiates into a large multinucleate cell called the ascogonium, which acts as the female gametangium.
- The ascogonium and antheridium fuse, forming a diploid (2n) ascus mother cell.
- The ascus mother cell undergoes meiosis, followed by mitosis, producing 08 ascospores.
- These 08 ascospores remain enclosed within asci, which are further enclosed in an ascocarp called a cleistothecium.
- At maturity, the cleistothecia rupture, releasing the ascospores.
- The ascospores germinate and develop into a haploid (n) vegetative mycelium, which can:
    1. Develop a conidiophore, producing conidia for asexual reproduction, or
    2. Re-enter the sexual reproduction cycle.

Life cycle: Monogenetic haplophase (single-generation, haploid-dominant life cycle).



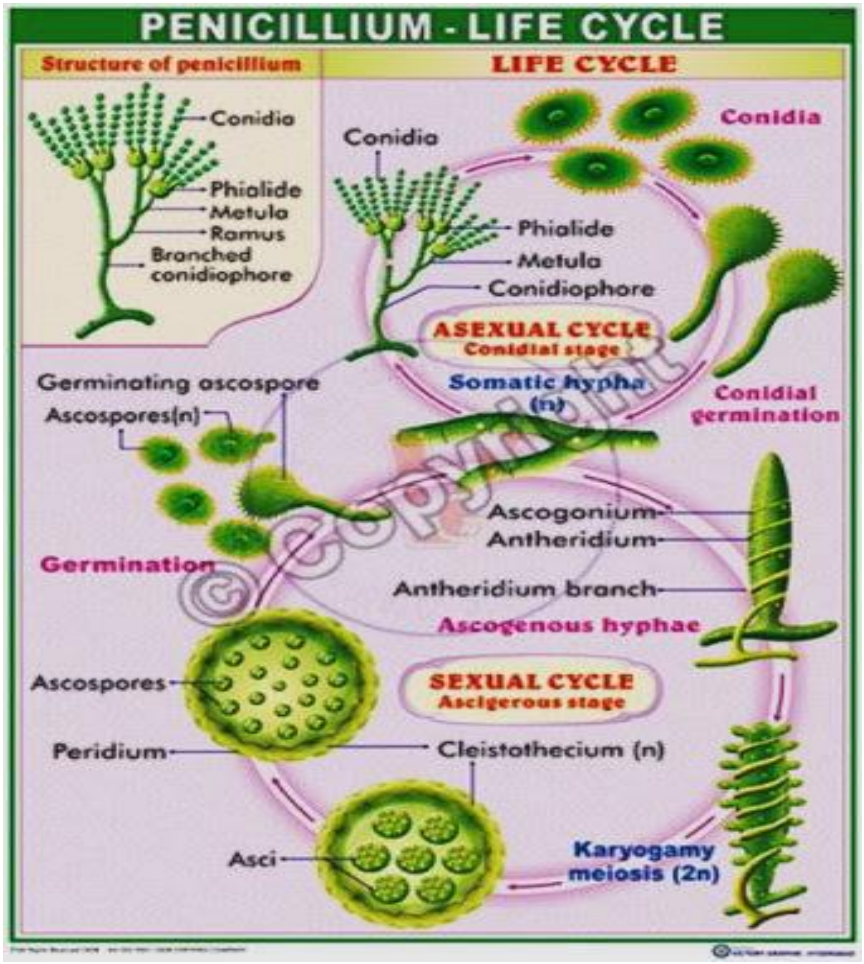


Figure: Sexual and asexual reproduction of some Genus of Penicillium

b- The Genus *Morchella*

• Taxonomy:

- **Kingdom:** Mycota
- **Phylum:** Ascomycota
- **Class:** Pezizomycetes
- **Subclass:** Pezizomycetidae
- **Order:** Pezizales
- **Family:** Morchellaceae
- **Genus:** *Morchella*

Figure : Morchella sp

• Description :

Morchella species, commonly known as morels, are fleshy, soil-dwelling, forest-associated, or grassland fungi. Their ascocarp (fruiting body) is hollow and consists of a fertile cap (receptacle), which is round, conical, or cylindrical, with deep honeycomb-like pits (alveoli).True morels are entirely hollow.

• Morphological variation:

- **Conical morels (*Morchella elata* group)** are generally small, rarely exceeding 10 cm, though some specimens can reach up to 20 cm.
    - Their white stalk is hollow.
    - Their cap is alveolate with a slightly rubbery texture.
- Two main groups can be distinguished based on color and shape:

1. **Blonde morels (*Morchella esculenta* group):** Their cap resembles a round sponge.
2. **Brown morels (*Morchella elata* group):** Their cap is more conical, with shallower alveoli.

Morels thrive in cool environments, preferring calcareous soils, orchards, debris piles, and recently burned areas.

• Reproduction of *Morchella*

▪ Asexual reproduction :

- Conidiospores germinate and develop into a haploid mycelium.
- This mycelium forms a conidiophore, which in turn produces new conidiospores, continuing the cycle.

▪ Sexual reproduction:

The life cycle of *Morchella* consists of **03** generations:

1. **First generation (Gametophytic stage)** – **Haploid Primary Mycelium**
    - A haploid primary mycelium develops.
    - On one primary mycelium, a male gametangium **(antheridium)** forms.
    - On another primary mycelium, a female gametangium **(ascogonium)** forms.
    - The two opposite-sex mycelia intertwine.
2. **Fertilization process :**
    - The male nuclei are transferred into the ascogonium through a trichogyne.
    - Inside the fertilized ascogonium, only the cytoplasms merge (**plasmogamy** occurs, but not nuclear fusion).

- This process produces a unique structure, a myctohaploid mycelium (containing paired but unfused male and female nuclei), representing the second generation (sporophyte).

3. **Second sporophytic generation – Dikaryotic mycelium (n+n)**
   - This new dikaryotic (n+n) mycelium consists of septate hyphae with paired, unfused nuclei.
   - At the tips of these dikaryotic hyphae, elongated ascus mother cells (sporocysts) form.
4. **Spore Formation :**
   - **Karyogamy** (nuclear fusion) occurs within the ascus mother cell, forming a diploid nucleus (2n).
   - This diploid nucleus undergoes meiosis, producing four haploid nuclei.
   - Each haploid nucleus undergoes mitosis, giving **08** haploid ascospores.
   - These ascospores are contained within asci, which are organized in the hymenium of the sporocarp (fruiting body).
   - The ascospores are eventually ejected through an operculum (a lid-like opening at the tip of the ascus).

• **Life Cycle Type:** This is a **trigenetic haplo-dikaryo-diplophasic cycle**, meaning it involves **03** distinct stages:

1. Haploid (n) gametophytic stage (primary mycelium).
2. Dikaryotic (n+n) sporophytic stage (secondary mycelium).
3. Diploid (2n) stage (ascus formation, followed by meiosis).

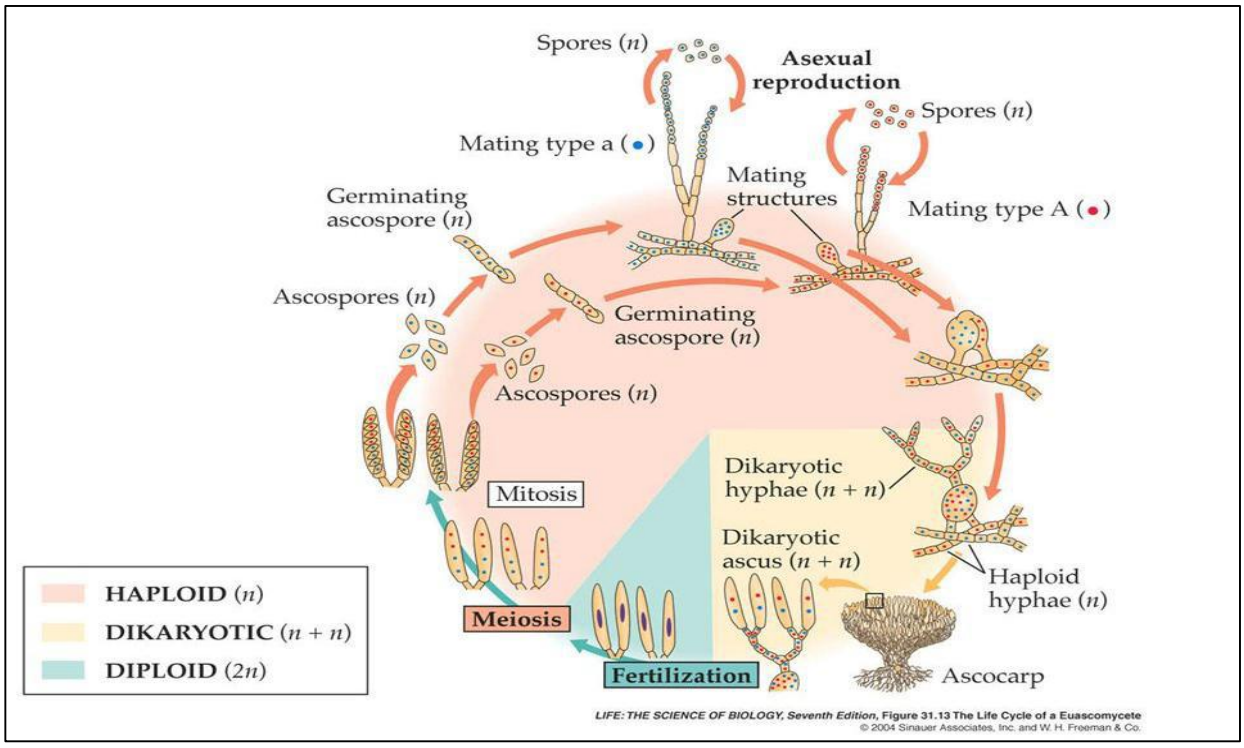


Figure : Morchella life cycle

3- The Zygomycetes:

a- Generalities:

The name of this phylum comes from **zygosporangia**, the resistant structures that form during sexual reproduction. Zygomycetes includes **1000 species**. They are molds, usually very discreet and microscopic in size. These fungi produce non-flagellated spores, and their hyphae are siphonous, containing multiple nuclei within the same filament. These fungi are also characterized by abundant asexual reproduction and rapid growth, allowing them to quickly colonize their environment. Many of them are parasites of plants or animals, while most live in terrestrial environments or on decaying plant or animal matter. Some Zygomycetes can associate with plant roots to form mycorrhizae.

There are **02 orders**, classified based on the number of spores they produce:

- A single spore (Entomophthorales)
- A large number of spores (Mucorales)

b- Reproduction:

Asexual Reproduction:

The spores germinate directly, giving rise to a new hypha, which forms a **zygosporangium** that releases spores.

Sexual Reproduction:

This occurs through **cystogamy**.

- Some species are **homothallic** (self-fertile), while others are **heterothallic** (self-sterile).
- In heterothallic species, sexual reproduction requires two physiologically compatible colonies (designated as **+** and **-**).
- Mycelia of opposite mating types produce extensions called **gametangia**, which contain multiple nuclei.
- The haploid gametangia fuse to form a **diploid zygosporangium**.
- This cell develops a thick, rough coating, allowing it to withstand harsh environmental conditions.
- When conditions improve, meiosis occurs.
- The zygosporangium germinates, producing small sporangia.
- Haploid spores are dispersed, germinate, and grow into new mycelia.

c- Example of Zygomycetes: The genus *Rhizopus*

Systematic classification :

- **Kingdom**: Mycota
- **Phylum**: Zygomycota
- **Subphylum**: Mucoromycotina
- **Class**: Zygomycetes
- **Order**: Mucorales
- **Family**: Mucoraceae
- **Genus**: *Rhizopus*

Figure: Rhizopus sp

Rhizopus is a genus of common molds that grow as filaments in soil, on fruits, decomposing plant material, and bread. It belongs to the order Mucorales. The hyphae of *Rhizopus* are siphonous (non-septate), multinucleate, haploid, and exhibit apical growth. Their cell walls contain chitin and glucans.

The protoplasm has numerous vacuoles that push the cytoplasm and nuclei to the periphery. Food reserves are stored as glycogen and lipids.

Reproduction in *Rhizopus*:

Asexual reproduction:

The spores, formed inside the sporocyst or sporangium, are released through the disintegration or rupture of the wall. Each spore can then germinate and develop into a new mycelial thallus.

Sexual reproduction:

Sexual reproduction occurs through **cystogamy**, following a haplophase monogenetic life cycle. Two opposite mycelial filaments grow toward each other under the influence of hormones and develop into multinucleate progametangia. After contact, a septum forms, separating each into a gametangium and a suspensor cell. The gametangial walls break down, allowing protoplast fusion to form a zygospores.

Inside the zygospore, haploid nuclei from both parents multiply by mitosis, but some degenerate. The remaining nuclei later pair up and undergo **karyogamy**, forming diploid nuclei. Eventually, only one diploid nucleus survives and undergoes meiosis, producing a single haploid nucleus. The zygospores enter dormancy until favorable conditions trigger germination, leading to the development of a new mycelium.

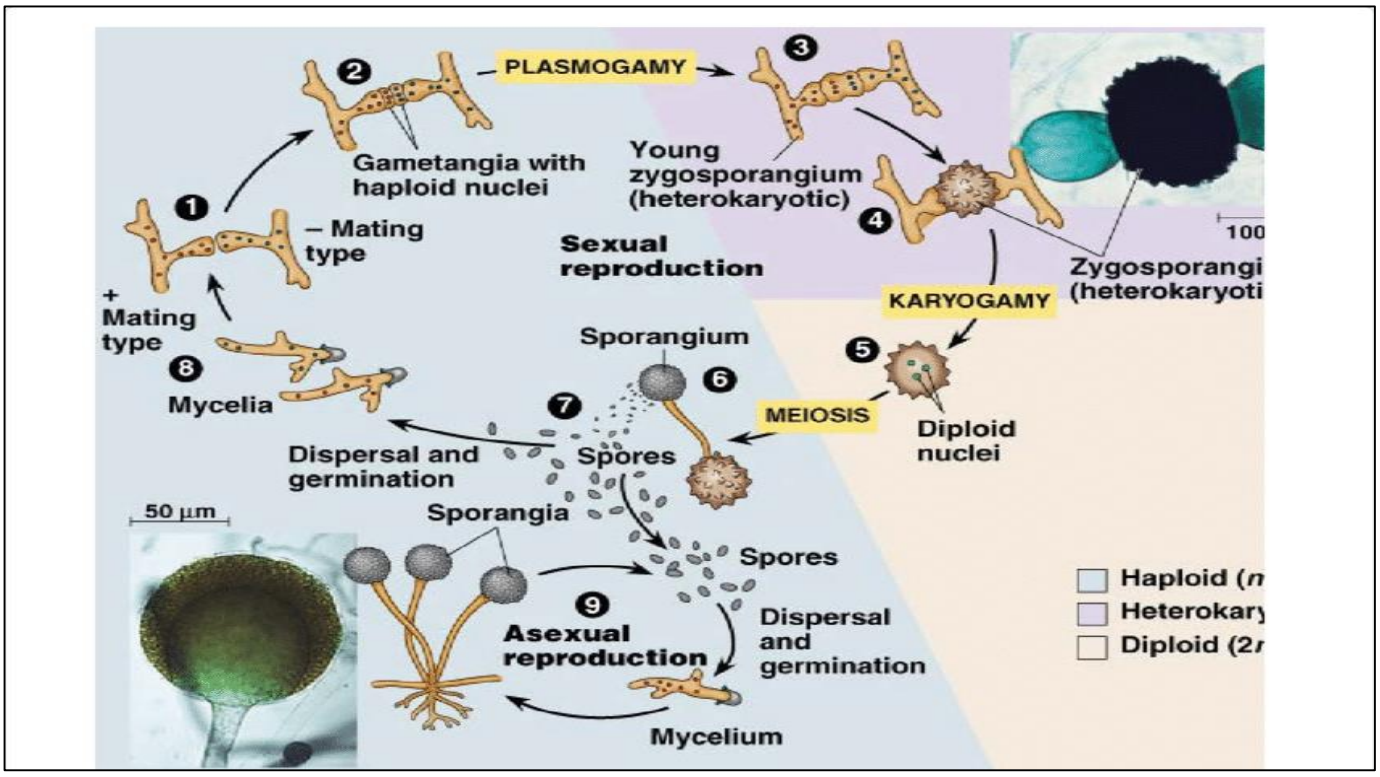


Figure : Reproduction of Genus Rhizopus

NOTE:

Glomeromycota is a **phylum** that was only recently separated from Zygomycetes. These are microscopic fungi and obligate mycorrhizae, playing a crucial role in plant communities. They form vesicular-arbuscular endomycorrhizae, the most widespread mycorrhizal association in nature, found in symbiosis with over 80% of vascular plants. No sexual reproduction has been identified in these fungi. They survive and propagate asexually through the formation of large encysted spores.

4- Basidiomycetes

a- General characteristics

Basidiomycota is a large phylum of fungi that includes most species commonly referred to as mushrooms. They are characterized by spores that form at the tip of specialized cells called basidia, located on carpophore structures (caps), and are dispersed by the wind upon maturity. These fungi are commonly known as “cap mushrooms” and can be classified based on morphological criteria (shape of the stipe and cap, texture of the flesh, spore color), organoleptic properties (odor and taste), and chemical composition.

The phylum includes approximately 25000 species, many of which are important decomposers of wood and plant material (e.g., boletes, agarics, Amanita species). The thallus consists of septate hyphae and

thrives in humus-rich soil, decaying plant matter, rotting wood, and leaf litter. Some microscopic basidiomycetes are phytopathogenic, causing plant diseases like rusts, or act as food spoilage agents.

The hymenium of basidiomycetes consists of numerous basidia that produce basidiospores, interspersed with sterile cystidia.

b- Reproduction

Asexual reproduction:

Asexual spores (conidia) are produced directly from mycelial filaments through simple cell division, although asexual reproduction plays a minor role compared to Ascomycetes.

Sexual reproduction:

Basidiomycetes are distinguished by their basidia, which are spherical structures located at the tips of specialized hyphae, typically beneath the mushroom cap (on gills, for gilled fungi).

Unlike asci in Ascomycetes, basidia do not contain sexual cells until maturity. Karyogamy (nuclear fusion) and meiosis occur within the basidium, transforming the diploid nucleus into four haploid nuclei, which then mature and form basidiospores.

The sexual process follows these steps:

- Hyphae of opposite mating types fuse.
- This results in a dikaryotic mycelium (containing two nuclei per cell), which grows faster and outcompetes the parental hyphae.
- When fully developed, the dikaryotic mycelium forms compact masses, which develop into a mushroom with a cap.
- Under the cap, basidia produce and release basidiospores, ensuring spore dispersal and reproduction.

The genus *Amanita*

1. Systematic Position

- **Kingdom**: Mycota
- **Phylum**: Basidiomycota
- **Class**: Agaricomycetes
- **Subclass**: Agaricomycetidae
- **Order**: Agaricales
- **Family**: Amanitaceae
- **Genus**: *Amanita*

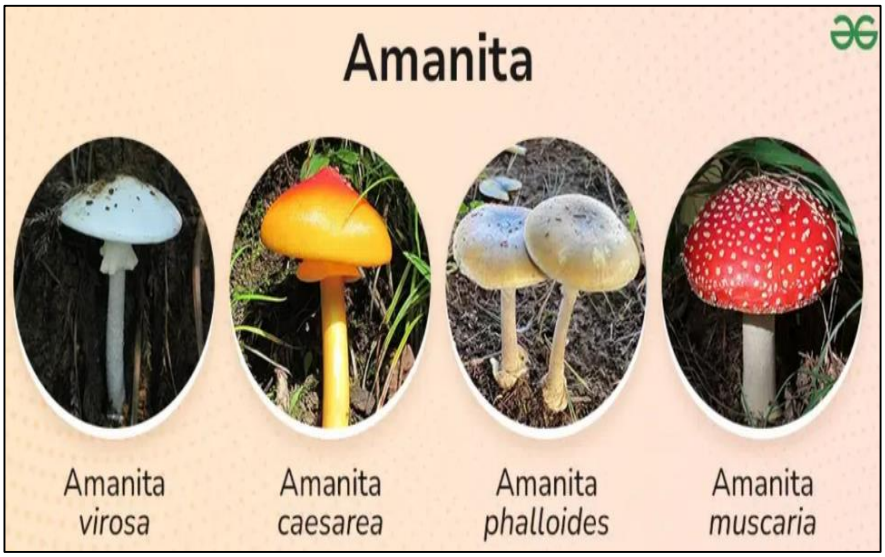


Figure : Genus Amanita

2. Description

The Amanita genus includes over 550 species, ranging from highly toxic to highly edible varieties.

- The fruiting body (sporophore) is a terrestrial mushroom with white spore print and free gills, typically white or sometimes yellow.
- The stipe (stem) is often bulbous and typically features a volva, which can be membranous or flaky and is sometimes difficult to see.
- A ring (annulus), often shaped like a collar or skirt, is present in young specimens but may disappear over time.
- The volva is a remnant of the universal veil, a protective layer that encloses the young mushroom. Initially, Amanita mushrooms appear as white eggs in their hypogeal stage (underground phase), similar to a chick inside an eggshell. As the mushroom grows, the volva splits open and remains at the base of the stem, sometimes in fragments.
- In some species, remnants of the volva remain on the cap as patches or warts.

3. Reproduction

Asexual reproduction

Asexual reproduction is rare in Basidiomycetes. It occurs when conidia (asexual spores) germinate and form a new mycelium, which later produces an aerial carpophore (fruiting body).

Sexual reproduction

Unlike Ascomycetes, Amanita species do not reproduce with differentiated sexual organs. Instead, reproduction occurs through a fusion of undifferentiated cells from two adjacent hyphae:

1. Plasmogamy: Two haploid mycelia of opposite mating types fuse their cytoplasm, forming a secondary dikaryotic mycelium (containing two nuclei per cell).
2. The dikaryotic mycelium grows rapidly, outcompeting the original parent mycelia.
3. Environmental factors like rain or temperature changes trigger the formation of compact masses that develop into basidiocarps (mushrooms).
4. The gill surface of the basidiocarp is lined with terminal dikaryotic cells called basidia.
5. Karyogamy occurs within the basidia, fusing the two nuclei to form a diploid nucleus.
6. The diploid nucleus undergoes meiosis, producing four haploid nuclei.
7. The basidium forms four projections, each receiving one haploid nucleus. These projections develop into basidiospores.
8. When mature, basidiospores are ejected from the basidia, fall from the mushroom cap, and disperse via wind, rain, or animal movement.
9. In suitable environmental conditions, the basidiospores germinate into haploid mycelia, completing the life cycle.

This is a digenetic haplodiplophasic cycle, alternating between haploid and diploid phases.

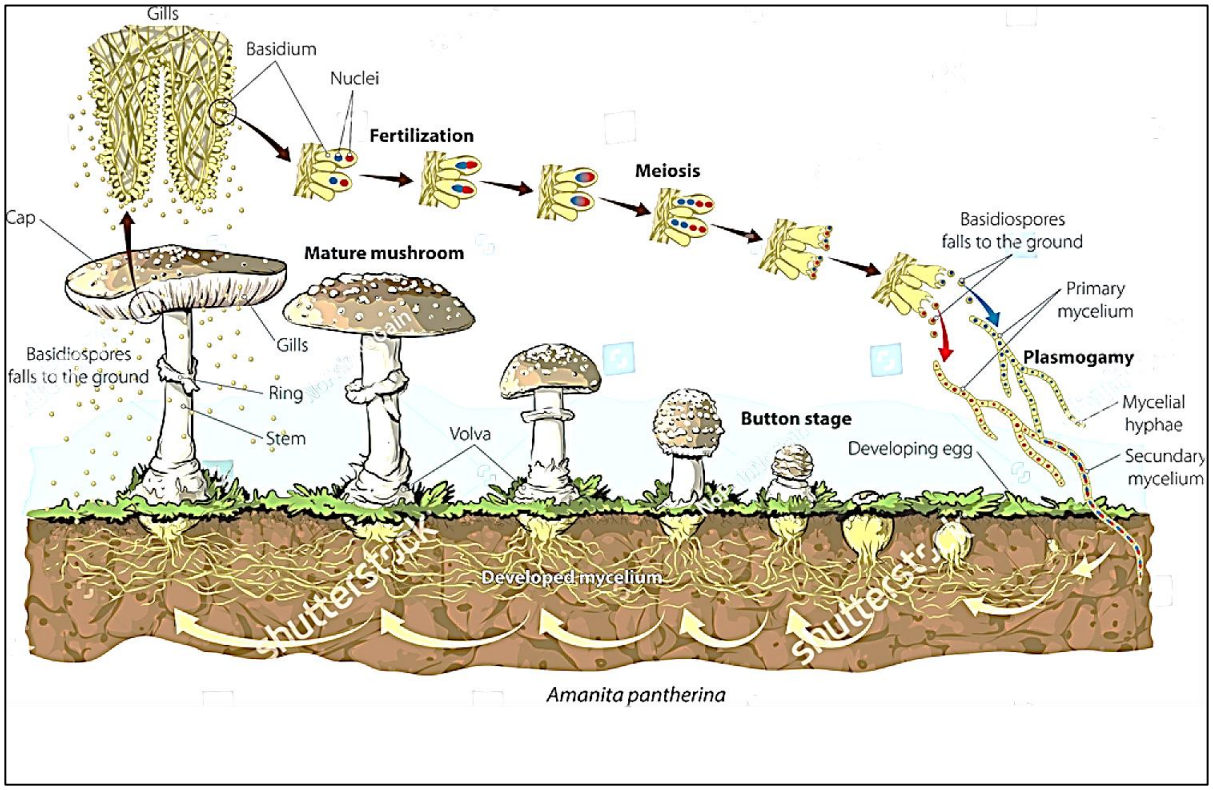


Figure: Life cycle of Amanita pantherina