

King Saud University  
College of Science  
Department of Botany and Microbiology



## MBI 531 Advanced Mycology

### Course Syllabus

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### What it the course about?

This is an advanced mycology master student course in Botany and Microbiology Department. In this class, the student will become familiar with the classification of fungi, their vegetative structure, fungi reproduction, lab diagnosis of fungal infection, opportunistic fungi, and useful properties of fungi.

The experiments, assignments, projects, and other activities in this course are designed to help students to learn the principles of microbial physiology, and report their presentation topic clearly and concisely, both in oral and written form. Students are expected to show up for class on time and be prepared for the class activities, work diligently, ask questions and participate in class discussions.

**Textbook:** There is no official text book for the course though there will be assigned readings from the primary literature below.

- Alcamo's Fundamentals of Microbiology 9th. Jeffrey C. Pommerville. 2010, Jones & Bartlett Learning. Sudbury, Massachusetts, USA.
- Microbiology, an evolving science. John W. Foster. 2009, W.W. Norton, N. Y., London.
- Essential Microbiology, Stuart Hoggy, 2005, John Wiley.

## Lecture Topics

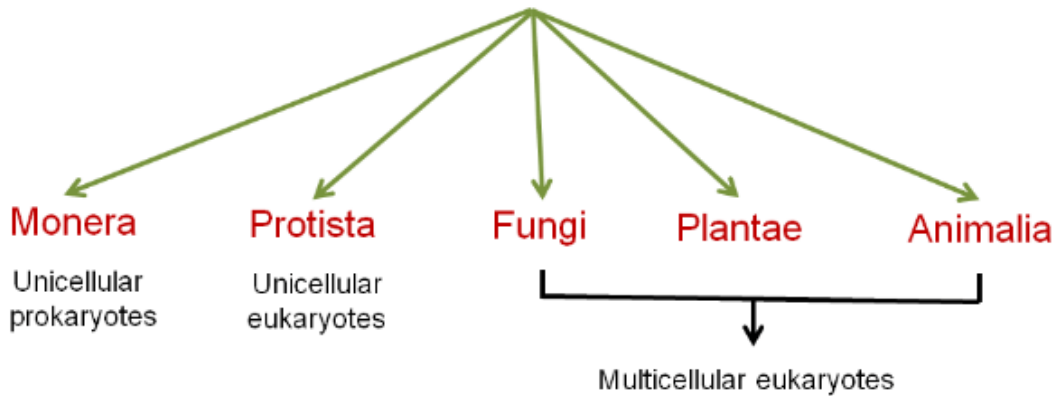
- Fungal identification, characterization and classification
- Fungal features and growth of hypha and mycelia formation
- Fungal growth on different media
- Characteristic of the fungi main groups
- Fungal genetics and genomics
- Fungi and biological control
- Applied field of fungi (in food, medicine and industry)
- Students presentation of new researches

### Fungal identification, characterization and classification

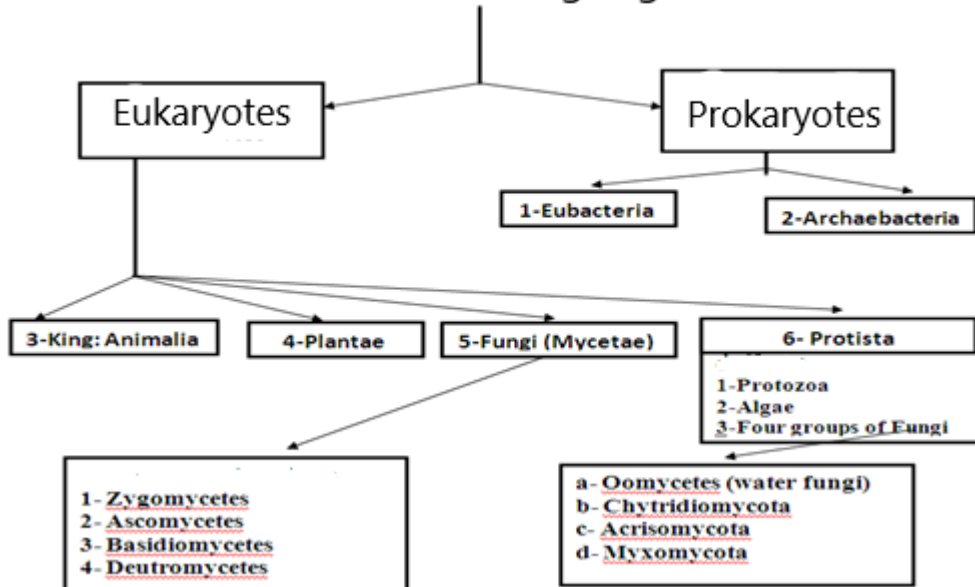
At first, biologists divided living organisms into two kingdoms: the Plantae kingdom and the Animalia kingdom. Then, in 1866, the German biologist Ernest Haeckel proposed the creation of a third kingdom limited to single-celled organisms, which he called the Protista kingdom. Then researchers noticed that Bacteria and Cyanobacteria are single-celled organisms that lack a true nucleus, and therefore they cannot be grouped with single-celled eukaryotes. Therefore, Copeland proposed in 1956 the establishment of a fourth kingdom, which he called Monera, which includes Prokaryotic organisms (bacteria and cyanobacteria).

In the 1960s, American biologist Robert Whittaker proposed a classification system based on five kingdoms: Monera (prokaryotes), Protista (chiefly protozoa and algae), Fungi (molds, yeasts, and mushrooms), Plantae (plants), and Animalia (animals). So in 1969 Whittaker separated the fungi into an independent kingdom, and placed the algae with the higher plants within the plant kingdom, and his classification of living organisms into five kingdoms, as briefly shown below. Then, in 1971, the scientist Margulis included all algae in the kingdom of Protista, and he also transferred some groups from the kingdom of fungi and from the kingdom of animals to the kingdom of Protista, all according to the following brief scheme:

Five kingdom classification of living organisms by  
R.H.Whittaker in 1969



Classification of living organisms



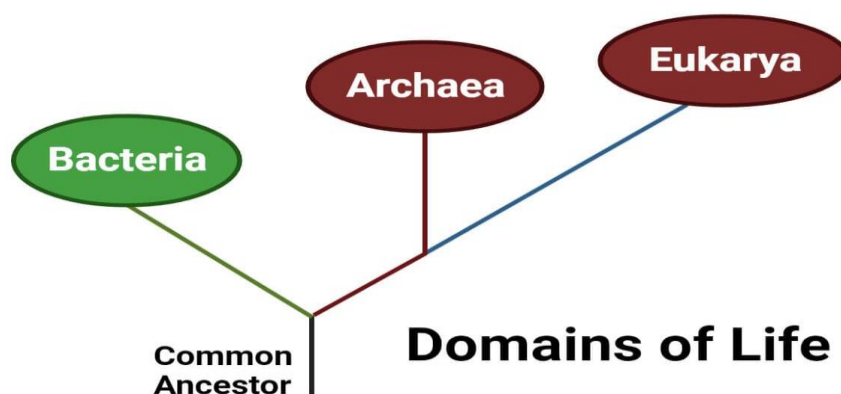
Archaea is a domain of life, together with Bacteria and Eukarya, containing single-celled prokaryotes other than bacteria. They are the oldest life-form known to exist. The name Archaea is derived from the Greek word '**ARCHAIOS**' meaning **primitive**. They show primitive living characteristics like simple structure, simple mode of nutrition acquisition and biochemistry, and extreme habitat.

Initially, under the two-kingdom system, Archaea were considered as types of bacteria and were included in the '**Prokaryota**' domain and were known by the name **Archaeobacteria**. However, biochemical and genetic studies reveal that Archaea have different metabolic characteristics and genetic constituents than that of Bacteria. In 1977, Carl Woese and George E. Fox first suggested Archaea be different from

bacteria based on their rRNA gene analysis and suggested they be different domains of life.

Archaea are microscopic, single-celled organisms lacking nuclei and other membrane-bound organelles like bacteria. Structurally they are similar to bacteria in their shape and size – microscopic with an average size of 0.1 to 15  $\mu\text{m}$ , coccoid, oval, or bacillus. However, some species are flattened and square (like *Haloquadratum walsbyi*) and may reach up to about 200  $\mu\text{m}$  or more. Like bacteria, Archaea are also aerobic, anaerobic, or facultative. Due to such structural resemblance, they were initially thought of as bacteria and were defined as Archaeobacteria.

Additional to these bacterial characteristics, Archaea also possesses characteristics of Eukaryotes. They show some genetic and metabolic characteristics similar to those of Eukaryotes.



The development of the three domains system revolutionized the classification of living organisms and provided a more accurate representation of the evolutionary relationships among them. The three domains system, proposed by Carl Woese and his colleagues, was based on molecular data, specifically the analysis of small subunit ribosomal RNA (16S rRNA). The development of this system can be outlined as follows:

### 1. Traditional Taxonomy:

- Before the three domains system, the classification of living organisms was primarily based on morphological and physiological characteristics. Organisms were traditionally categorized into two main groups: Prokaryota (bacteria) and Eukaryota (eukaryotes, including plants, animals, fungi, and protists).

### 2. Discovery of Archaea:

- In the 1970s, Carl Woese and his team started studying the genetic material (RNA) of various organisms, focusing on the small subunit ribosomal RNA (16S rRNA). This molecule was chosen because it is universally present in all cells and evolves relatively slowly.

- During their research, they discovered that the genetic sequences of certain microorganisms previously classified as bacteria were significantly different from other bacteria. These microorganisms were later identified as a distinct group and named Archaea.

### **3. Proposal of the Three Domains System:**

- In 1977, Carl Woese and George Fox published a groundbreaking paper proposing the division of life into three primary domains based on molecular data: Bacteria, Archaea, and Eukarya. This was a significant departure from the traditional two-domain system.

- The Three Domains System recognizes that Archaea are a distinct group separate from Bacteria and more closely related to Eukarya. This system is supported by the molecular phylogenetic analysis of 16S rRNA, highlighting the evolutionary relationships among organisms.

### **4. Key Features of Each Domain:**

- Bacteria (Domain Bacteria):

- Unicellular prokaryotic organisms.

- Diverse shapes and sizes.

- Lack membrane-bound organelles.

- Some are extremophiles (organisms thriving in extreme environments).

- Archaea (Domain Archaea):

- Unicellular prokaryotic organisms.

- Share some features with bacteria but are genetically and biochemically distinct.

- Include extremophiles, but also organisms found in more moderate environments.

- Unique membrane lipids and cell wall components compared to bacteria.

- Eukarya (Domain Eukarya):

- Include diverse organisms with complex cell structures.

- Membrane-bound organelles, including a nucleus.

- Includes plants, animals, fungi, and protists.
- More complex multicellular organisms compared to Bacteria and Archaea.

### **5. Acceptance and Impact:**

- The three domains system has been widely accepted and is now the standard framework for classifying living organisms.

- It has provided a more accurate representation of the diversity and evolutionary relationships among all living things.

- Molecular techniques continue to refine our understanding of the relationships within and between the domains.

The development of the three domains system represents a major milestone in the history of biological classification, emphasizing the importance of molecular data in understanding the evolutionary relationships among organisms.

[The major factor stimulating the development of the three-domain system in biology was the advancement in molecular biology and the discovery of the archaea domain.](#)

Traditionally, the classification of living organisms was based on observable characteristics such as morphology, anatomy, and metabolism. However, with the advent of molecular techniques like DNA sequencing, scientists were able to study the genetic material of organisms in much greater detail.

In the 1970s and 1980s, Carl Woese and his colleagues conducted pioneering research on the small subunit ribosomal RNA (16S rRNA) sequences. They found that there were significant differences in the genetic sequences of bacteria and what was then considered as a single group of microorganisms known as "archaebacteria." This led to the proposal of a new classification system with three domains: Bacteria, Archaea, and Eukarya.

The discovery of the archaea domain challenged the traditional view that all prokaryotic organisms belonged to a single group (bacteria). The recognition of archaea as a distinct domain highlighted the diversity of life at the molecular level and emphasized the need for a revised classification system. The three-domain system, which distinguishes bacteria, archaea, and eukaryotes based on genetic and cellular characteristics, became widely accepted and is now a fundamental framework in modern biology.

## The fungi characteristics and their relevance to fungi taxonomy

Fungi are a diverse group of eukaryotic organisms that play crucial roles in ecosystems as decomposers, symbionts, and pathogens. The characteristics of fungi and their relevance to taxonomy include:

### 1. Cell Structure:

- Eukaryotic Cells: Fungi have complex cells with membrane-bound organelles, including a nucleus.

- Cell Wall: Fungal cell walls contain chitin, a unique complex sugar, which distinguishes them from other eukaryotes.

### 2. Nutrition:

- Heterotrophic: Fungi are primarily heterotrophic, obtaining their nutrients by absorbing organic material from their surroundings.

- Saprophytic: Many fungi are saprophytic, breaking down and absorbing nutrients from dead organic matter.

### 3. Reproduction:

- Asexual and Sexual Reproduction: Fungi exhibit both asexual and sexual reproduction. Asexual reproduction involves spore formation, while sexual reproduction involves the fusion of specialized sexual structures (gametes).

### 4. Morphology:

- Multicellularity: Fungi can be unicellular (yeasts) or multicellular (molds and mushrooms).

- Hyphal Structure: Most fungi have thread-like structures called hyphae, which form a network called mycelium. The organization of hyphae is critical for taxonomy.

### 5. Lifecycle:

- Dikaryotic Stage: During sexual reproduction, fungi often have a dikaryotic stage where cells contain two different but compatible nuclei.

- Zygotic Meiosis: The fungal life cycle typically involves zygotic meiosis, where the zygote undergoes meiosis to produce haploid spores.

## **6. Ecological Roles:**

- Decomposers: Fungi play a crucial role in decomposing organic matter, recycling nutrients in ecosystems.

- Mycorrhizae: Many fungi form mutualistic relationships with plants, called mycorrhizae, aiding in nutrient absorption.

- Pathogens: Some fungi are plant and animal pathogens causing diseases.

## **7. Taxonomic Classification:**

- Major Phyla: Fungi are classified into major phyla based on reproductive structures, life cycles, and molecular data. Common phyla include Ascomycota, Basidiomycota, Zygomycota, and others.

- Molecular Techniques: Advances in DNA sequencing and molecular techniques have revolutionized fungal taxonomy, allowing for more accurate classification based on genetic data.

Understanding these characteristics is crucial for accurately classifying fungi into their respective taxonomic groups. Molecular techniques have particularly enhanced our ability to discern relationships between different fungal species and refine their taxonomic classifications.

### **Some fungi have more than one scientific name.**

The occurrence of multiple scientific names for a single fungus is primarily due to historical reasons, changes in taxonomic understanding, and the evolution of scientific knowledge. This phenomenon is known as synonymy in the field of taxonomy. Several factors contribute to the existence of multiple names for the same fungus:

#### **1. Historical Taxonomic Practices:**

- Over time, different researchers may have described and named the same fungus independently without being aware of each other's work. This can result in the assignment of multiple names to the same species.



## 2. Revisions in Classification:

- Advances in molecular biology and DNA sequencing have led to a better understanding of the evolutionary relationships among organisms. As a result, the classification of fungi, like other organisms, has undergone revisions. Taxonomists may reevaluate species relationships and redefine genera, leading to changes in scientific names.

## 3. Species Complexes:

- Some fungi exist as species complexes, where what was once considered a single species is later found to be a group of closely related species with subtle differences. As a result, different names may have been assigned to various members of the complex.

## 4. Different Life Stages:

- Fungi often have different stages in their life cycles, including asexual and sexual stages. Historically, these different stages may have been described as separate species, leading to multiple names for what is now known to be the same organism.

## 5. International Code of Nomenclature:

- The rules of the International Code of Nomenclature for algae, fungi, and plants (ICNafp) govern the naming of fungi. Changes or updates to the Code, as well as adherence to its rules, may lead to the recognition of one name over another, resulting in the synonymy of certain names.

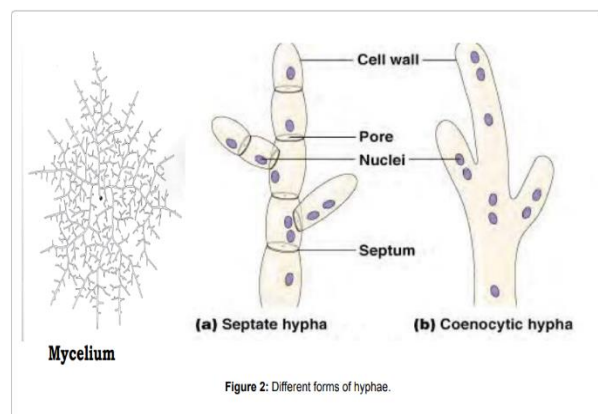
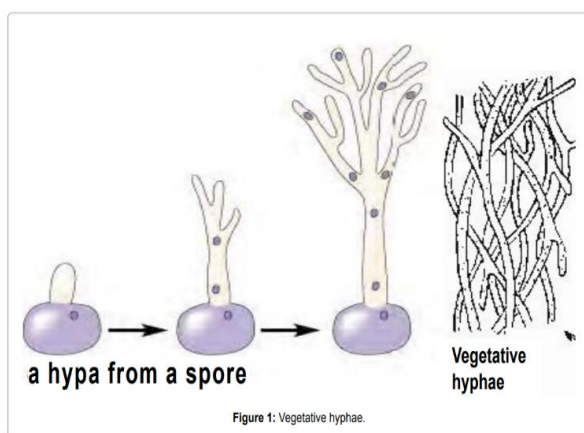
Efforts are made within the scientific community to standardize and update nomenclature to reflect the most accurate and current understanding of fungal taxonomy. The use of molecular techniques and collaborative research has helped to clarify relationships among fungi and reduce the occurrence of synonymous names. The mycological community also maintains databases and resources to track and reconcile different names for the same fungal species.

## **Fungal features and growth of hypha and mycelia formation**

The basic cellular units of fungi described as hyphae (singular: hypha). Hyphae of fungi may be branched and their dense mass called as mycelium.

### Cell biology of the fungi

Hypha form is usually a tubular cell developed from growing spore (Figure 1) and surrounded by a rigid, chitin-containing cell wall. The hypha extends by tip growth, and multiplies by branching, creating a fine network called a mycelium. Hyphae contain all organs including nuclei, mitochondria, ribosomes, Golgi and membrane-bound vesicles within a plasma membrane bound cytoplasm. The sub-cellular structures supported and organized by microtubules and endoplasmic reticulum. 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). Septa (cross-walls), if present, usually been observed down a light microscope. Some fungi possess septa (that divide the hyphae into separate cells) 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 or more pores - such septa divide the hyphae into a series of interconnected hyphal compartments, rather than separate, discrete cells. Coenocytic hyphae lack septa (Figure 2).



### Fungal growth

Fungi, like every living thing, need energy and food sources to complete their development and life cycles after sexual and asexual reproduction. These food sources are carbon, nitrogen, vitamins, and minerals.

They also need suitable environmental conditions (such as pH, temperature, humidity, oxygen) to grow and develop. Fungi can consume vegetable and animal carbon sources thanks to their hydrolytic enzymes. They can use monosaccharides and polysaccharides such as glucose, fructose, chitin, cellulose, hemicellulose, and lignin. Like all living things

Fungi need a nitrogen source for their growth and development, and fungi can metabolize many different nitrogen sources. Especially ammonium and glutamine are the first nitrogen sources they use. In addition, they can easily use other nitrogen sources.

Vitamins are cofactors of enzymes and growth factors of many organisms. Fungi need vitamins for their growth and development. Some of these vitamins are; thiamine, biotin, riboflavin, nicotinic acid, vitamin K and pantothenic acid.

Like many microorganisms, fungi can survive in varying environmental conditions and under various stress factors. They can survive and reproduce in extreme environments, such as the poles, in extremely cold regions, and in extremely hot regions such as deserts. Fungi are generally; grow better in warm, acidic, and aerobic environments, but they can survive in cold, alkaline, and anaerobic environments. Although the growth temperatures of the fungi are quite wide, the best growth is seen at 25°C.

Fungi that live under the temperature at which they develop optimally are called psychrotolerant, and fungi that live at temperatures of 40°C and above are called thermotolerant fungi. Fungi that live in or are exposed to temperatures above 40°C can survive by protecting themselves from heat stress by producing heat shock proteins.

Fungi can be found in yeast or mold structures depending on the temperature of the environment they are in, and fungi with this feature are called dimorphic fungi. One of the most important fungi showing this feature is *Histoplasma* sp.

If the place where it is located in an environment of 25°C, it develops as a mold with a hyphae structure that can reproduce vegetatively, and as yeast if the environment is 37°C.

This feature allows them to survive in different ecosystems and even to continue their generation. The pH value, which is important for the realization of many biochemical reactions in all living things, is one of the important environmental conditions for fungi. Some fungi can survive and even reproduce at pH1 and 13, which are extreme for many organisms. Most fungi survive and reproduce between pH3 and 10. The optimum pH range is between 5 and 7.

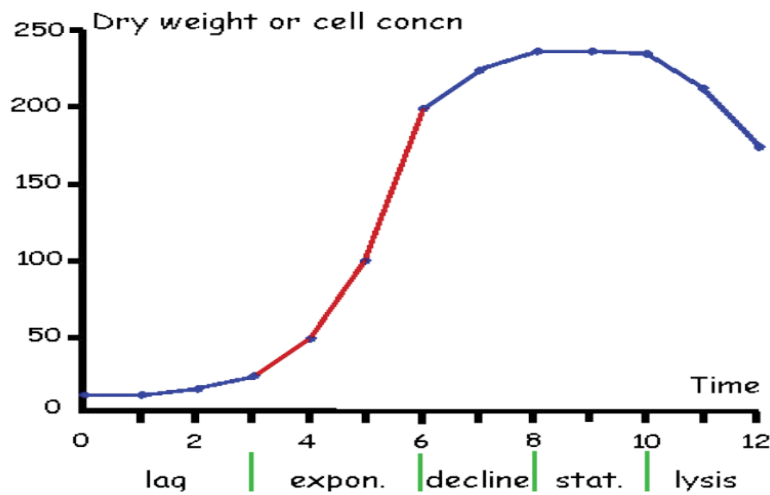
In addition, if the environment in which fungi are found is alkaline, they can achieve maximum growth by converting the pH of the environment to the optimum growth pH with the organic acids they secrete. Abiotic stress factors such as water, UV, and heavy metals affect the development of fungi as well as all organisms. In particular, UV-B radiation, which is more biologically harmful, negatively affects the growth and development of fungi. Fungi are among the largest and most diverse groups of eukaryotic organisms. Because of their complex gene structure, the enzymes they produce, and their ability to use many different carbon sources.

### **Characteristic S-shaped growth curve**

Rate of growth or cell division is very slow. Fungal cell adapts themselves to growth conditions. It is the period where the individual fungi are maturing and not yet able to divide. During this phase of the fungal growth cycle, synthesis of RNA, enzymes and other molecules occurs. So in this phase the fungal cell is not dormant.

Growth or cell division then starts to accelerate into the exponential phase - when, for example, with a unicellular organism (e.g. yeast species) any one cell produces two in a given period of time, those 2 produce 4, the 4 produce 8, 8 produce 16 and so on. This exponential phase (central red region in the graph opposite) represents the period when the fungus is growing or multiplying most rapidly. The actual rate of this growth depends upon the growth conditions, which affect the frequency of cell division events and the probability of both daughter cells surviving. This phase will continue until one or more nutrients become limiting, oxygen becomes depleted and/or metabolic by-products accumulate to toxic levels.

Growth will start to decelerate (decline). This may be followed by a stationary phase, during which there is no discernible change in cell concentration or biomass. This phase (stationary phase) is a constant value as the rate of fungal growth is equal to the rate of fungal death. Finally, cell death and lysis which results in a decrease in cell number and/or biomass were, observe a phase



## Fungal features and growth of hypha and mycelia formation

Fungi are fascinating organisms with complex growth structures and developmental processes. Here's a brief overview of fungal features and the formation of mycelium and hyphae.

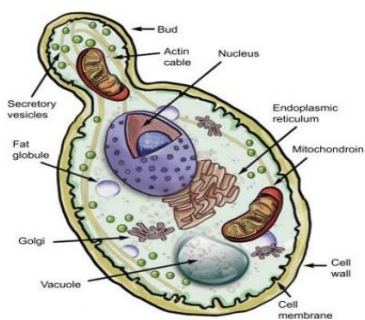


Figure : (a) Morphology of yeast

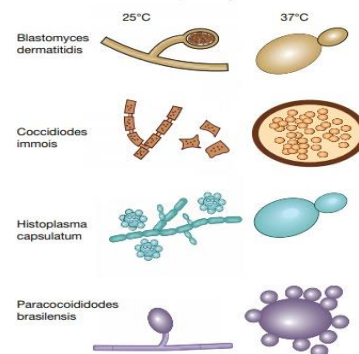
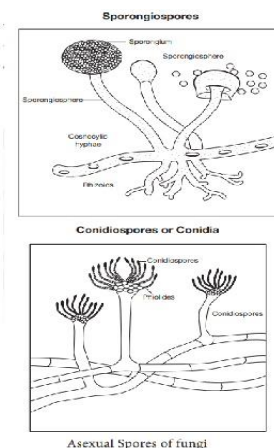
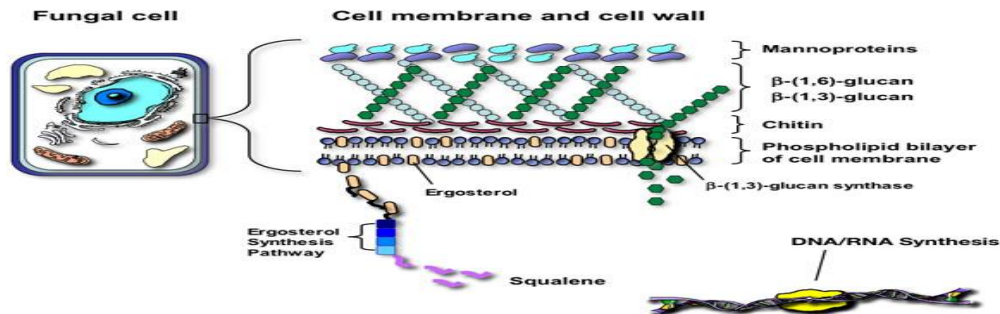


Figure : Dimorphic Fungi



## Fungal Features

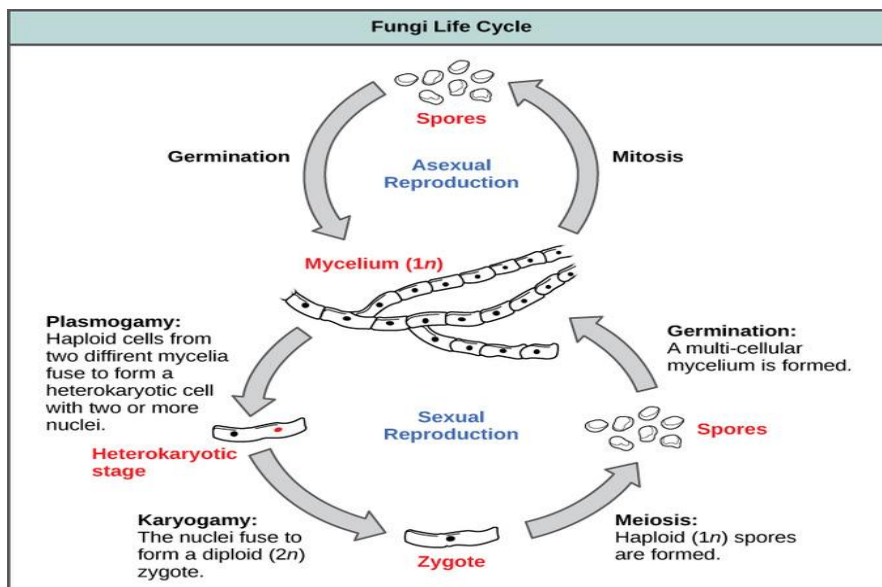
**Cell Walls:** Fungal cell walls are primarily composed of chitin, a polysaccharide, which differentiates them from plant cell walls made of cellulose.



**Heterotrophic Nutrition:** Fungi absorb nutrients from organic matter through external digestion, releasing enzymes into their environment and then absorbing the resultant smaller molecules.



**Reproduction:** Fungi reproduce both sexually and asexually. Asexual reproduction often involves the production of spores, while sexual reproduction involves the fusion of specialized sexual structures.

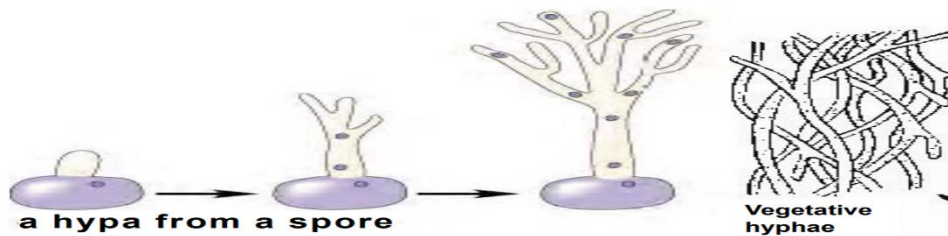


## Hypha Formation

Hyphae are the fundamental structural units of fungi. They are long, filamentous structures that grow from a spore or a fragment of mycelium.

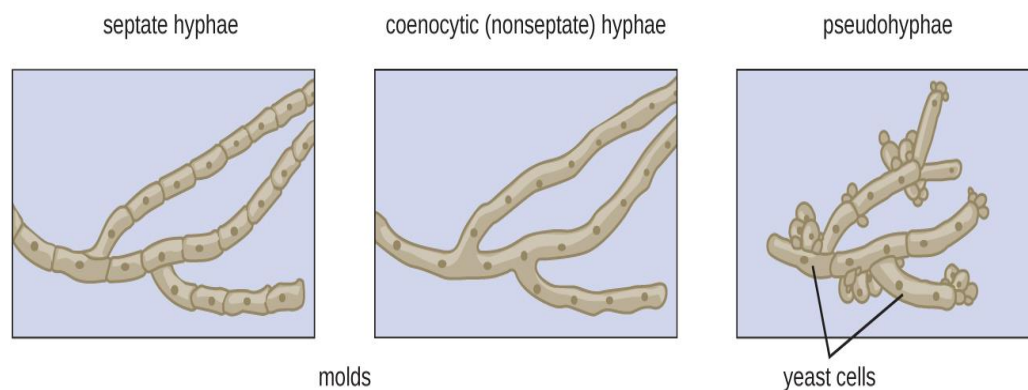
### Growth:

Hyphae grow at their tips through a process called apical growth. As they extend, they absorb nutrients from the surrounding environment. The growth is directed by the presence of nutrients and environmental conditions.



### Types of Hyphae

Hyphae can be septate (with cross-walls dividing them into cells) or coenocytic (without septa, forming a continuous multinucleate structure).

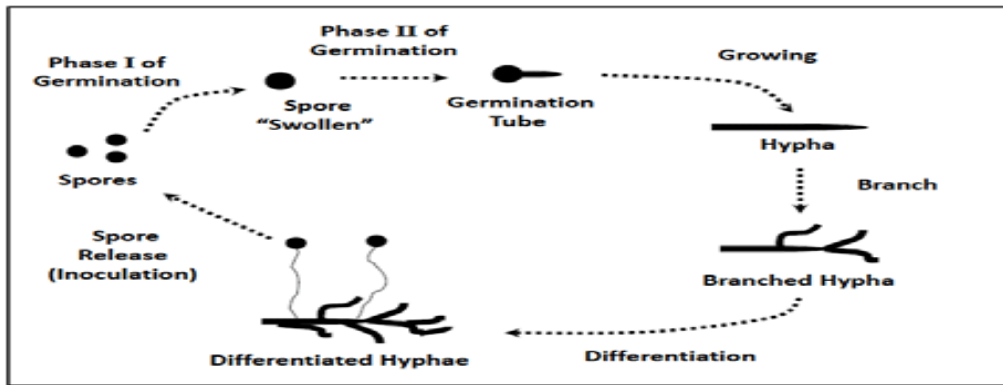


### Mycelium Formation

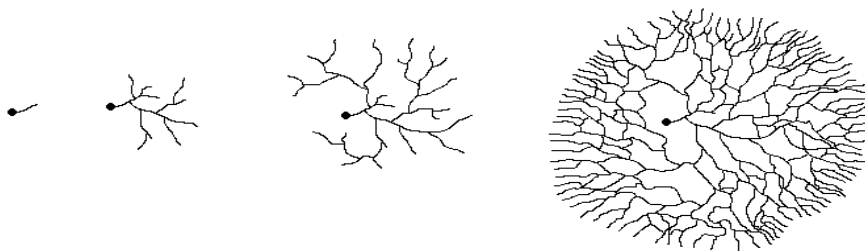
Mycelium is the network of hyphae that forms the vegetative part of a fungus. It plays a critical role in nutrient absorption and overall growth.

### Formation:

When fungal spores germinate, they produce hyphae that spread out and branch extensively, forming a dense and intricate network called mycelium. This network allows the fungus to explore and exploit its environment effectively.



**Structure and Function:** Mycelium can be highly branched and expansive, adapting its structure to environmental conditions and the availability of nutrients. It can also form specialized structures like rhizomorphs to transport nutrients over long distances.



## Fungal hypha structure

Fungal hyphae (singular: hypha) are long, branching, thread-like structures that make up the body (mycelium) of multicellular fungi. They play a crucial role in growth, nutrient absorption, and reproduction. The structure of a fungal hypha includes:

- 1. Cell Wall:** Composed mainly of chitin (a strong, flexible polysaccharide), which gives rigidity to the hypha and protection from external forces.
- 2. Septa:** Hyphae are divided into compartments by cross walls called septa, though some fungi may have non-septate (coenocytic) hyphae, which lack septa and have a continuous cytoplasm with multiple nuclei. Septa often have pores that allow organelles and nutrients to pass between cells.
- 3. Cytoplasm and Organelles:** Each hyphal compartment contains cytoplasm, with organelles like mitochondria, endoplasmic reticulum, and nuclei. In coenocytic fungi, these organelles can move freely throughout the entire length of the hypha.
- 4. Apical Growth:** Hyphae grow at their tips (apices) in a process called apical growth. Vesicles containing enzymes and cell wall materials accumulate at the tip, leading to the extension of the hypha.



**5. Spitzenkörper:** A specialized structure involved in directing the growth of the hyphal tip, made of vesicles and proteins, playing a key role in transporting materials needed for the growth of the hypha.

Hyphae are the main growth form of many fungi and are essential for their ability to penetrate substrates and absorb nutrients, allowing the fungus to thrive in various environments.

## Fungal growth on different media

Fungal growth can be studied on various types of media, each of which can provide different nutrients and conditions suitable for different fungi. Here are some common types of media used for culturing fungi and their characteristics:

<b>Potato Dextrose Agar (PDA)</b>	<b>Malt Extract Agar (MEA)</b>
This media is rich in nutrients and is often used for growing fungi and yeasts. The potato extract provides polysaccharides that promote growth, while dextrose serves as an energy source. PDA is especially good for isolating and cultivating pathogenic fungi.	MEA is particularly favorable for yeast and fungal cultures as it provides a high sugar content. It is commonly used for isolating fungi in food and beverage microbiology, particularly brewing.

<b>Sabouraud Dextrose Agar (SDA)</b>	<b>Czapek Dox Agar</b>
This medium is made of peptones and dextrose, which allows for the growth of a wide variety of fungi and yeasts. It has a low pH, which inhibits bacterial growth, making it ideal for mycological studies.	This medium contains various salts and sugar sources that are best for fungal species that rely on specific carbon and nitrogen sources, such as the genus <i>Aspergillus</i> and <i>Penicillium</i> .

<b>Chloramphenicol Agar</b>	<b>Potato Carrot Agar (PCA)</b>	<b>Yeast Extract Peptone Dextrose (YPD) Agar</b>	<b>Luria-Bertani (LB) Agar</b>
This selective medium can be used to isolate fungi while inhibiting bacterial growth due to the antibiotic chloramphenicol.	This medium is particularly good for isolating fungi from soil and plant material and is known for promoting the growth of a variety of fungi, including saprophytic molds.	This complex medium is widely used for yeast and mold cultures, providing a rich nutrient environment that supports the growth of various fungi.	While primarily used for bacteria, LB agar can sometimes support the growth of fungi, particularly those that have close relationships with their bacterial counterparts.

When isolating and studying fungal growth, it's essential to adjust incubation temperatures, humidity, and light exposure according to the specific requirements of the fungal species being studied. Each medium may yield different morphological and growth characteristics, making them useful for identification and research purposes.

## characteristics of the fungi main groups

Fungi are a diverse group of organisms, and they are generally classified into several main groups based on their life cycle, reproduction, and other characteristics. Here are the main groups of fungi and their key characteristics:

### 1. Chytridiomycota (Chytrids)

- Habitat: Primarily aquatic, but some are terrestrial.
- Reproduction: Mostly asexual via motile zoospores, which have a single flagellum.
- Unique Feature: They are the only fungi with flagellated spores.
- Ecological Role: Some are saprophytic, breaking down organic material, while others are parasitic, including on amphibians (e.g., *Batrachochytrium dendrobatidis*).

### 2. Zygomycota (Zygoete Fungi)

- Habitat: Mostly terrestrial, found in soil or decaying plant and animal matter.
- Reproduction: Asexual reproduction via sporangia that release sporangiospores; sexual reproduction results in the formation of zygospores after the fusion of specialized cells.
- Ecological Role: Many are decomposers (saprotrophs), but some are parasites or symbionts.
- Example: *Rhizopus* (black bread mold).

### 3. Ascomycota (Sac Fungi)

- Habitat: Found in various environments, from soil and decaying material to symbiotic relationships (e.g., lichens).
- Reproduction: Asexual reproduction is common through conidia (asexual spores); sexual reproduction involves the formation of asci, where spores (ascospores) develop.
- Ecological Role: Many are decomposers, while others form mutualistic relationships (lichens), and some are parasitic.
- Examples: Yeasts (*Saccharomyces*), morels, truffles, and some plant pathogens like *Claviceps purpurea* (ergot).

#### **4. Basidiomycota (Club Fungi)**

- **Habitat:** Wide-ranging, typically terrestrial, found in forests, grasslands, and on decaying organic matter.
- **Reproduction:** Sexual reproduction involves the formation of basidia, where basidiospores are produced.
- **Ecological Role:** Includes decomposers (especially of wood), plant pathogens, and mycorrhizal species that form mutualistic relationships with plant roots.
- **Examples:** Mushrooms, puffballs, shelf fungi, and rusts.

#### **5. Glomeromycota**

- **Habitat:** Typically found in soil and associated with plant roots.
- **Reproduction:** Asexual, forming large, thick-walled spores.
- **Ecological Role:** Most are arbuscular mycorrhizal fungi (AMF), forming symbiotic relationships with plant roots, assisting in nutrient uptake (especially phosphorus).
- **Unique Feature:** They form arbuscules within plant root cells, which is a characteristic feature of their symbiotic relationship.

#### **6. Deuteromycota (Imperfect Fungi)**

- **Habitat:** Diverse habitats, often found in soil, water, or decaying matter.
- **Reproduction:** Asexual reproduction only (hence the name “imperfect”), usually by conidia.
- **Ecological Role:** Many are saprophytes, but some are important pathogens of plants, animals, and humans.
- **Examples:** Penicillium, Aspergillus, and various human pathogens like Candida.

#### **Summary of Ecological Roles:**

- **Decomposers:** Break down dead organic material, returning nutrients to the environment.
- **Symbionts:** Form mutualistic relationships, particularly with plants (mycorrhizae).
- **Pathogens:** Cause diseases in plants, animals, and humans.
- **Food and Medicine:** Some fungi are used in food production (e.g., yeast) and pharmaceuticals (e.g., penicillin).

Each group plays a vital role in ecosystems and human industries, from breaking down dead matter to providing antibiotics and food products.

## Fungal genetics and genomics

Fungal genetics and genomics is the study of how fungi inherit traits and how their genetic material is organized, replicated, and expressed. This field has significant implications in biotechnology, medicine, agriculture, and ecology, as fungi play crucial roles as decomposers, pathogens, and symbionts. The era of fungal genomics was ushered in by the sequencing of the complete genome of the yeast *S. cerevisiae*, reported in 1996. This milestone revolutionized work in yeast and enabled the first global studies of eukaryotic gene function and expression. However, the yeast genome sequence provided only a limited glimpse of the biological diversity of the fungal kingdom. The progress in sequencing fungal genomes was initially slow. Accelerated by the luncheon of Fungal Genome Initiative (FGI).

The genome of fungi includes all the genetic information encoded by the chromosomal genes and extrachromosomal components. Each of these can contribute significantly to the phenotype of fungi. Regarding the fungal chromosomes and chromosomal genes most fungi are haploid, but the Oomycota are diploid. A few fungi can alternate between haploid and diploid somatic phases, and some yeasts (e.g. *Candida albicans*) are permanently diploid

Mitochondrial genome of fungi contain a small circular DNA of varying sizes. Fungal mitochondrial genomes are often in the range of 19–121 kb. The mitochondrial DNA of fungi has relation to aging; because in several filamentous fungi (*Podospora*, *Neurospora*, *Aspergillus*) a single mutation in a single mitochondrion can lead to senescence of the whole colony. Most fungal plasmids are found in the mitochondria. They include the linear DNA plasmids of *Neurospora crassa* and *N. intermedia*. They show a degree of sequence homology to the mitochondrial genome (??defective, excised segments of the mitochondrial genes). Some other mitochondrial plasmids of *Neurospora* are closed circular molecules with little or no homology to the mitochondrial genome. They do not code for antibiotic resistance or pathogenicity.

### Key Areas in Fungal Genetics and Genomics:

- 1. Genomic Structure:** Fungal genomes vary widely in size and complexity. They generally have small, compact genomes with fewer repetitive sequences compared to plants and animals. The genome contains genes responsible for their metabolic diversity, pathogenicity, and symbiotic relationships.
- 2. Gene Regulation:** Fungi possess sophisticated regulatory networks controlling gene expression, allowing them to adapt to various environments. This includes responses to nutrient availability, temperature,

and stress. Epigenetic mechanisms (e.g., histone modification and DNA methylation) also play roles in gene regulation.

**3. Sexual and Asexual Reproduction:** Fungi can reproduce both sexually and asexually. Sexual reproduction involves genetic recombination, contributing to genetic diversity, while asexual reproduction allows for rapid population expansion. Many fungi can switch between these modes depending on environmental conditions.

**4. Horizontal Gene Transfer (HGT):** HGT plays a role in the evolution of certain fungal species. It allows for the acquisition of new traits, such as antibiotic resistance or the ability to degrade complex polymers, which can be important for survival in diverse environments.

**5. Pathogenicity and Virulence Factors:** Fungal pathogens (like *Candida*, *Aspergillus*, and *Cryptococcus*) have specialized genes that facilitate infection and survival in host organisms. Genomics helps identify these virulence factors, aiding in the development of antifungal drugs and therapies.

**6. Secondary Metabolites:** Fungi produce a vast array of secondary metabolites, including antibiotics (like penicillin) and mycotoxins. The genes involved in the biosynthesis of these compounds are often clustered in the genome, and genomics helps in identifying and manipulating these clusters for pharmaceutical and industrial applications.

**7. Comparative Genomics:** By comparing the genomes of different fungal species, researchers can infer evolutionary relationships, identify conserved genetic pathways, and understand how fungi adapt to their environments.

**8. Functional Genomics:** Techniques such as CRISPR-Cas9, RNA interference (RNAi), and transcriptomics are used to study the function of genes and how they contribute to fungal physiology, pathogenicity, and ecological roles.

## **Applications:**

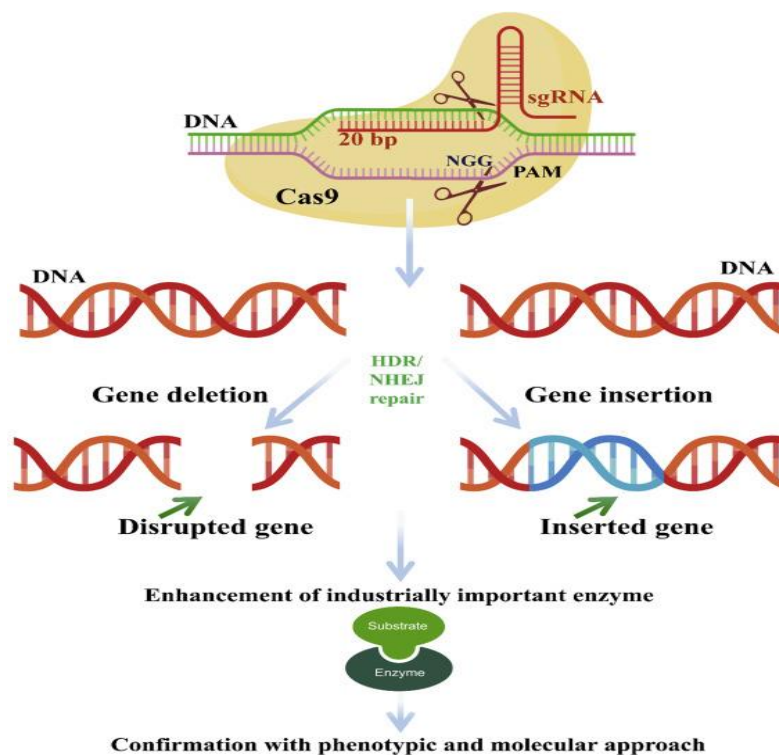
- **Biotechnology:** Fungi are used in the production of enzymes, biofuels, and pharmaceuticals. Understanding fungal genetics can enhance the efficiency of these processes.
- **Medicine:** Genomic insights into pathogenic fungi can lead to the development of better diagnostic tools and treatments for fungal infections.

- Agriculture: Genomic studies of mycorrhizal fungi and plant pathogens contribute to sustainable agriculture by improving crop resistance and soil health.

Fungal genomics is a rapidly advancing field with the increasing availability of sequencing technologies, enabling deeper insights into the complexity and versatility of fungal organisms.

## Using CRISPR technology in genetic modification of fungi

In filamentous fungi, CRISPR-Cas editing of genes is primarily accomplished via the NHEJ and HDR pathways to repair double-strand breaks (DSBs) caused by Cas protein splicing.



## Fungi and biological Control

Nowadays, use of a fungal biocontrol agent (BCA) is considered to be a rapidly developing natural phenomenon in research area with implications for plant yield and food production. Fungal biocontrol agents (BCAs) do not cause any harm to the environment, and they generally do not develop resistance in various types of insects, pests, weeds, and pathogens due to their complex mode of action. They have been proved to be an alternative against the undesirable use of chemical pesticides. The advantage of fungi to be used as biological control agents is that they need not be ingested by the insect hosts, but they can invade directly through the insect's cuticle and control all insect pests including sucking insects, but in the case of viruses and bacteria, this is not possible. The present literature includes mechanisms of fungal biological control agents, advantages and limitations of BCAs, and list of commercially available BCAs against the insects, pests, weeds, nematodes, and plant pathogens.

### 1. Pathogenic Fungi Against Pests

- **Insect Pathogens:** Certain fungi act as pathogens to insects and other arthropods. For example, *Beauveria bassiana* and *Metarhizium anisopliae* are used to control a variety of insect pests.
- **Nematode Control:** *Paecilomyces lilacinus* and *Verticillium chlamydosporium* are effective against plant-parasitic nematodes.

### 2. Fungal Antagonists Against Plant Pathogens

- **Mycoparasitism:** Some fungi act as mycoparasites, attacking other pathogenic fungi. For instance, *Trichoderma* species are well-known for their antagonistic properties against soil-borne plant pathogens.
- **Disease Suppression:** *Gliocladium* and *Coniothyrium* species are used for suppressing diseases like *Fusarium* wilt and other fungal infections in crops.

### 3. Biological Control in Integrated Pest Management (IPM)

Fungal Applications in IPM: Integrating fungal biological control agents with other pest management strategies can enhance crop protection and reduce reliance on chemical pesticides.

### 4. Commercial Use and Development

- **Product Development:** Various commercial products utilize fungal biological control agents for agricultural pest management. These products are formulated as spores or mycelial preparations.
- **Regulatory and Efficacy Considerations:** Understanding the regulatory landscape and efficacy of fungal biocontrol agents is crucial for their successful deployment.

## **Applied fields of fungi in food, medicine and industry**

Fungi play an important and multifaceted role in the production and processing of food, influencing various stages from cultivation to consumption. Fungi serve as essential agents in food cultivation, aiding in the breakdown of organic matter and the recycling of nutrients, and promoting plant growth through symbiotic relationships. Moreover, fungi such as yeasts and molds are integral to fermentation processes, yielding a wide array of fermented foods and beverages with unique flavors and textures. Additionally, fungi are indispensable in the creation of enzymes and bioactive compounds utilized in food processing, enhancing the nutritional value, shelf life, and safety.

The role of fungi in the development of medicine has largely been studied. The early recognition of the germ theory was discussed in relation to surface infections, the “cholera fungus theory” and recognition of the phenomenon of microbial antagonism. This leads to a consideration of the role of those antibiotics produced by fungi, notably penicillin.

The Fungi kingdom describes several species characterized by various forms and applications. They can be found in all habitats and play an essential role in the excellent functioning of the ecosystem, for example, as decomposers of plant material for the cycling of carbon and nutrients or as symbionts of plants. Furthermore, fungi have been used in many sectors for centuries, from producing food, beverages, and medications. Recently, they have gained significant recognition for protecting the environment, agriculture, and several industrial applications.

### 1. Food Industry

- **Fermentation:** Fungi play a crucial role in fermentation processes. Yeasts, such as *Saccharomyces cerevisiae*, are used in baking to leaven bread and in brewing to produce alcoholic beverages. Other fungi, like *Aspergillus oryzae*, are used in the production of soy sauce and miso.
- **Mycoprotein:** *Fusarium venenatum* is used to produce mycoprotein, a high-protein, meat substitute found in products like Quorn.

### 2. Medicine



■ Antibiotics: The discovery of penicillin, derived from *Penicillium notatum*, revolutionized medicine. Other antibiotics such as cephalosporins are also fungal-derived.

■ Immunosuppressants: Cyclosporine, derived from *Tolypocladium inflatum*, is crucial in preventing organ rejection in transplant patients.

■ Antifungals: Drugs such as fluconazole and itraconazole are used to treat fungal infections. These are often derived from or modeled after fungal metabolites.

### 3. Industry

■ Biodegradation: Saprophytic fungi are good biodegraders. Through their enzymatic activities, they can degrade any organic substances. Most of the time during the processes of degradation, macrofungi (mushrooms) are observed as per the climatic conditions prevailing in the particular locations.

■ Enzyme Production: Recently, fungi have been used for the production of more than 50% of the needed enzymes. Fungi can produce different types of enzymes extracellularly, which gives a great chance for producing in large amounts with low cost and easy viability in purified forms using simple purification methods.

■ Biofuels: The production of the first and second generation of biofuels is often based on the principle of conversion of a long-chain glucose polymer to monomers, which can be fermented into ethanol. Fungi are primary decomposers that secrete exoenzymes to degrade complex biomass into monomeric sugars.

These references should provide a solid foundation for understanding the diverse applications of fungi in food, medicine, and industry.

## The useful properties of fungi

Fungi exhibit a wide range of useful properties that make them valuable to humans and ecosystems. Some of the notable beneficial properties of fungi include:

### 1. Decomposition and Recycling:

- Fungi play a crucial role in breaking down complex organic matter, such as dead plants and animals. They are primary decomposers in ecosystems, recycling nutrients and contributing to soil fertility.

### 2. Mycorrhizal Symbiosis:

- Many fungi form symbiotic relationships with plant roots known as mycorrhizae. These associations enhance nutrient absorption by plants, particularly phosphorus and nitrogen, and contribute to improved plant growth.

### 3. Biological Pest Control:

- Some fungi act as biological control agents against pests and pathogens. For example, certain fungal species can be used as biopesticides to control insect pests in agriculture.

### 4. Fermentation and Food Production:

- Fungi are essential in various food and beverage production processes. Yeasts, for instance, are used in fermentation to produce bread, beer, wine, and other fermented products.

### 5. Medicine Production:

- Antibiotics such as penicillin, discovered from the fungus *Penicillium*, revolutionized medicine by providing effective treatments for bacterial infections. Many other fungi also produce compounds with medicinal properties.

### 6. Bioremediation:

- Some fungi have the ability to break down or absorb pollutants and contaminants. This makes them valuable in bioremediation efforts to clean up environmental pollution.

### 7. Biotechnological Applications:

- Fungi are used in various biotechnological processes. For example, certain fungi are employed in the production of enzymes, organic acids, and biofuels.

### 8. Textile and Paper Industry:

- Enzymes produced by fungi are used in the textile industry for processes like biofinishing, where they improve the properties of fabrics. Fungi are also involved in the production of paper and pulp.

### 9. Research and Biomedical Studies:

- Fungi serve as important model organisms in scientific research. Studies on fungi provide insights into fundamental biological processes, genetics, and molecular biology.

#### 10. Edible Fungi:

- Many fungi are edible and serve as important food sources. Examples include mushrooms like *Agaricus bisporus* (button mushroom) and *Pleurotus ostreatus* (oyster mushroom).

#### 11. Industrial Enzyme Production:

- Fungi are used in the production of various industrial enzymes, including amylases, cellulases, and proteases, which find applications in diverse industries such as food, textile, and biofuel production.

Understanding and harnessing these beneficial properties of fungi contribute to advancements in agriculture, medicine, industry, and environmental sustainability. However, it's important to note that while some fungi are highly beneficial, others can be pathogenic and cause diseases in plants, animals, and humans.

### **Dimorphic fungi occur in two forms**

Dimorphic fungi are fungi that can exist in two different morphological forms during their life cycle, usually shifting between a mold (filamentous) form and a yeast form. The ability to undergo this dimorphic transition is often associated with changes in environmental conditions, such as temperature. The two primary forms of dimorphic fungi are:

#### 1. Mold (Filamentous) Form:

- In the mold form, these fungi typically grow as a mass of thread-like structures known as hyphae. The hyphae collectively form a mycelium, which is the vegetative, filamentous structure of the fungus. This form is more common in the environment and at lower temperatures.

#### 2. Yeast Form:

- In the yeast form, the fungi exist as single-celled organisms. The cells are typically round to oval in shape. This form is often associated with higher temperatures, usually the temperature of the host organism. The yeast form is more commonly found during the infective phase when these fungi cause diseases in animals or humans.

The ability to switch between these two forms allows dimorphic fungi to adapt to different host environments and facilitates their survival and pathogenicity. Many dimorphic fungi are significant human pathogens, causing diseases known as mycoses. Examples of dimorphic fungi include:

- *Histoplasma capsulatum*: Causes histoplasmosis and exists as a mold in the environment, converting to a yeast form in host tissues.
- *Blastomyces dermatitidis*: Causes blastomycosis and also undergoes a mold-to-yeast transition.
- *Coccidioides immitis* and *Coccidioides posadasii*: Cause coccidioidomycosis and exhibit a similar dimorphic life cycle.

Understanding the dimorphic nature of these fungi is crucial for studying their biology, pathogenicity, and developing strategies for diagnosis and treatment of associated infections.

### **Opportunistic fungi infection.**

An opportunistic infection is an infection caused by pathogens (usually microorganisms like bacteria, viruses, fungi, or parasites) that typically do not cause illness in healthy individuals with intact immune systems. Instead, these infections take advantage of weakened immune defenses or altered host conditions to establish an infection and cause disease. The term "opportunistic" reflects the fact that these pathogens opportunistically exploit a host's vulnerability.

Key points about opportunistic infections include:

1. **Host Susceptibility:** Opportunistic infections often occur in individuals with compromised immune systems. This can result from conditions such as HIV/AIDS,

immunosuppressive therapies (e.g., after organ transplantation), certain medical treatments (chemotherapy), or underlying diseases that affect the immune system.

## 2. Pathogen Types:

- Bacteria: Examples include species like *Pneumocystis jirovecii*, which can cause pneumonia in immunocompromised individuals.

- Viruses: Cytomegalovirus (CMV) and Epstein-Barr virus (EBV) are examples of viruses that can cause opportunistic infections in people with weakened immune systems.

- Fungi: *Candida* and *Aspergillus* species are common opportunistic fungal pathogens.

- Parasites: *Toxoplasma gondii* is an example of a parasitic opportunistic pathogen.

3. Clinical Manifestations: Opportunistic infections can manifest in various ways depending on the type of pathogen and the site of infection. Common sites include the respiratory system, gastrointestinal tract, central nervous system, and skin.

4. Preventive Measures: Preventing opportunistic infections often involves managing the underlying immunosuppressive condition and, in some cases, using prophylactic antimicrobial drugs. For example, people with HIV may take antiretroviral medications to control viral replication and reduce the risk of opportunistic infections.

5. Diagnostic Challenges: Diagnosing opportunistic infections can be challenging because they may present atypically or mimic other conditions. Healthcare providers often need to consider a patient's immunological status and perform specific diagnostic tests to identify opportunistic pathogens.

It's important for healthcare professionals to be vigilant about opportunistic infections in individuals with compromised immune systems and to tailor treatment strategies accordingly. Early detection and appropriate management are crucial for improving outcomes in individuals at risk for opportunistic infections.

## **Fungal infections / mycoses.**

Fungal infections, also known as mycoses, are diseases caused by various types of fungi. Fungi are a diverse group of microorganisms that can be found in the environment, and while most fungi are harmless to humans, some have the potential to cause infections. Fungal infections can affect various parts of the body, ranging from superficial skin infections to systemic infections that involve internal organs. The severity of fungal infections can vary, and they may be acute or chronic.

### **Types of Fungal Infections:**

#### 1. Superficial Mycoses:

- Location: These infections affect the outermost layers of the skin, hair, and nails.
- Examples: Tinea (ringworm) infections, such as athlete's foot (Tinea pedis), ringworm (Tinea corporis), and fungal nail infections (onychomycosis).

#### 2. Cutaneous Mycoses:

- Location: Infections that involve the skin, hair, and nails but extend deeper than superficial mycoses.
- Examples: Dermatophytosis, which includes infections caused by dermatophyte fungi like Trichophyton, Microsporum, and Epidermophyton.

#### 3. Subcutaneous Mycoses:

- Location: These infections involve the tissues just below the skin surface, including muscles and connective tissues.
- Examples: Sporotrichosis caused by the fungus *Sporothrix schenckii*, and mycetoma caused by various fungi.

#### 4. Systemic Mycoses:

- Location: Infections that can affect internal organs and may spread throughout the body.
- Examples:

- Histoplasmosis caused by *Histoplasma capsulatum*.
- Coccidioidomycosis caused by *Coccidioides immitis* or *Coccidioides posadasii*.
- Cryptococcosis caused by *Cryptococcus neoformans*.
- Blastomycosis caused by *Blastomyces dermatitidis*.
- Aspergillosis caused by *Aspergillus* species.

#### 5. Opportunistic Mycoses:

- Host Susceptibility: These infections typically occur in individuals with weakened immune systems.

- Examples:

- Candidiasis caused by *Candida* species, which can affect mucous membranes and internal organs.

- Aspergillosis in immunocompromised individuals.

- Pneumocystis pneumonia (PCP) caused by *Pneumocystis jirovecii*, often seen in individuals with HIV/AIDS.

#### **Common Risk Factors for Fungal Infections:**

1. Immunosuppression: Weakened immune systems due to conditions such as HIV/AIDS, organ transplantation, or immunosuppressive medications.

2. Diabetes: Individuals with diabetes are more susceptible to certain fungal infections, particularly those affecting the skin and nails.

3. Poor Hygiene: Fungi thrive in warm, moist environments, and poor hygiene can contribute to the development of superficial fungal infections.

4. Environmental Exposure: Activities such as gardening, farming, or construction work can expose individuals to environmental fungi.

5. Use of Antibiotics or Steroids: Prolonged use of antibiotics or corticosteroids can disrupt the balance of microorganisms in the body and contribute to fungal overgrowth.

### **Diagnosis and Treatment:**

- Diagnosis: Fungal infections are diagnosed through clinical examination, laboratory tests (such as microscopy, culture, and molecular techniques), and sometimes imaging studies.

- Treatment: Antifungal medications, including topical creams, oral medications, or intravenous drugs, are used to treat fungal infections. The choice of treatment depends on the type and severity of the infection.

### **Prevention:**

- Maintaining Good Hygiene: Regular handwashing, keeping the skin dry, and avoiding sharing personal items can help prevent fungal infections.

- Avoiding Environmental Exposure: Using protective gear in environments where fungal exposure is likely can reduce the risk.

- Managing Underlying Health Conditions: Properly managing conditions that weaken the immune system, such as HIV/AIDS or diabetes, is essential in preventing opportunistic fungal infections.

Fungal infections can range from mild and easily treatable to severe and life-threatening. Early diagnosis and appropriate treatment are crucial for a successful outcome. Individuals with persistent or worsening symptoms should seek medical attention for proper evaluation and management.