## Introduction to Fungi

**Fungi** (singular **fungus**) – Fungi can be defined as **nucleated**, **achlorophyllous**, **osmotrophic, spore-bearing** organisms that typically reproduce both sexually and asexually and whose usually branching, filamentous bodies are surrounded by cell walls composed of cellulose, chitin or both.

The science or study of fungi is called **mycology** (mykes = mushroom), and originated as the study of macroscopic organisms such as mushrooms, puffballs and bracket fungi. These organisms were often collected as food items, but the ingestion of toxic fungi sometimes resulted in fatality and sometimes caused peculiar neurological reactions "they did funny things to the head". It was important that people collecting fungi knew something about them.

Fungi are classified within the domain **Eukarya**, and according to the Whittaker five-kingdom system are categorized within the kingdom **Fungi** (**Myceteae**); although other references divide them between the kingdoms **Chromista** and **Eumycotina**.

Fungi are eukaryotic organisms with true nuclei surrounded by nuclear envelopes. They are equipped with a variety of organelles, but unlike plants do not have chloroplasts. The term **achlorophyllous** means without chlorophyll (a = without, chlorophyll = green, light-sensitive pigment). Green pigments are commonly associated with light-trapping ability in green plants, algae, cyanobacteria and other phototrophic organisms, but fungi do not have this ability. Fungi are nutritionally categorized as **chemoheterotrophs** (like us).

**Chemoheterotrophs** (chemo = chemicals, hetero = different, troph = feeding or activity), are organisms capable of using preformed organic compounds for both energy and carbon. Fungi are **osmotrophic** chemoheterotrophs, which means they take in nutrients in liquid form. Fungi digest their food or nutrient materials outside their bodies by dumping digestive enzymes into their environments. Once the food has been broken into smaller components (molecules) it can readily be taken into the fungus cells. Most fungi are **saprotrophs** (sapros = rotten), and use dead or decaying organic material for food; these forms are also called decomposers. Some fungi are parasites (living on other live organisms) and some are pathogens (causing disease symptoms).

Fungi can be divided into three general categories (yeasts, molds and fleshy fungi) based on their morphology; however, it should be noted that many types of fungi can change form and do so on a regular basis. **Yeasts** are single-celled fungi with growth habits similar to bacteria, i.e., when grown on nutrient media form circular, convex, smooth-shiny colonies in various colors. Molds are filamentous fungi with microscopic, thread-like morphology. When grown on nutrient media they form fuzzy, hair-like masses that often extend considerably above the agar (sometimes filling the entire container). Fleshy fungi are those forming macroscopic fruiting bodies commonly encountered in gardens, fields and forests during periods of wet weather. Though these appear solid, they are also composed of filaments, so are structurally similar to molds.

The body of a mold-type or fleshy fungus (body = soma or thallus) is made up of microscopic, thread-like filaments called **hyphae** (singular = hypha). Hyphae grow and extend outward from each germinating fungus spore (reproductive body) and penetrate into whatever nutrient material is available to them. As the hyphae multiply, they eventually form a filamentous mass or mat visible to the naked eye, and this is called a **mycelium** (pleural = mycelia). As the mycelium matures, it can be divided into two regions with separate and specific functions. That portion of the mycelium extending down, into the nutrient material is called the **vegetative mycelium** and is involved in food getting. That portion extending upward into the air is called the **aerial mycelium** and is reproductive. The blue-colored mass on the surface of a rotting orange or the gray, fuzzy-looking mass on the surface of a rotting strawberry is aerial mycelium. If the blue-colored mass is on the surface of your favorite cheese, remember it is being supported by a vegetative mycelium extending below the surface. Whether to eat or not to eat is a personal decision.

Hyphae are composed of multiple nucleated cells surrounded by cell walls, but these may or may not be separated, i.e., hyphae may be either **septate** or **aseptate**. Septate hyphae have crosswalls or **septa** (singular = septum) between the individual cells, while aseptate hyphae do not. Sometimes the cells of septate hyphae contain two separate, haploid nuclei each and are called **dikaryons** (dikaryon = two nuclei). The cells of aseptate hyphae are not separated by crosswalls, so obviously form a true **syncytium**, i.e., a multinucleated mass of protoplasm. The crosswalls of septate hyphae are not complete because they have holes in them (like lifesavers), so the cells of septate hyphae form a true syncytium also. This is significant because materials can readily move from cell to cell within a fungus, and the hyphae of the vegetative mycelium can share nutrients with those of the aerial mycelium.

The wall materials formed by fungus cells are polysaccharide, usually cellulose, chitin, glucan or a combination of these.. Walls provide support and protection for the protoplasm, and give the fungi their characteristic shape (single-celled Vs filamentous). Though all mold-type and fleshy fungi have hyphae, the size of these structures vary considerably. Some hyphae are truly microscopic and only visible with the aid of microscopy, while others are thick, hair-like and may grow to be several inches in length.

**Specialized types of hyphae:**

The hyphae associated with vegetative mycelia differ from those associated with aerial mycelia in terms of function, but both types can be divided into still more specific categories depending on where they are found. Some specific examples of specialized hyphae are listed below.

1. Hyphae supporting different types of asexual spores can be named in association with the spores they support, for example **sporangiophores** support the sac-like **sporangia** containing **sporangiospores** and **conidiophores** support the bead-like **conidiospores** developing at the ends of phialids.

2. **Haustoria** – Haustoria (haust = to suck) are specialized hyphae produced by parasitic fungi. These penetrate into the cytoplasm of host cells and absorb nutrients. Many fungi considered as plant pathogens form haustoria.

3. **Mycorrhizae** –Mycorrhizae are specialized hyphae allowing fungi to form mutualistic relationships with the roots of forest trees and other plants. Some mycorrhizae (**endomycorrhizae**) penetrate root cells and others (**ectomycorrhizae**) wrap around the root surface, but both types share materials with their plant hosts. Mycorrhizae help plants absorb minerals (primarily phosphorous) and water from soil, while the fungi obtain nutrients (primarily sugar) from the plant. The fungi also produce chemicals (antibiotics) that help protect the plant from infection by bacteria. This is an important symbiotic relationship, and without their fungal symbionts, many plants cannot develop properly, cannot reproduce, and sometimes die.

**Fungus Reproduction:**

Most fungi reproduce both sexually and asexually, although asexual reproduction is a simpler process and much more common. Fungus cultures maintained under laboratory conditions will reproduce asexually over and over again and only form sexual structures under specific conditions. (Would you believe soft music and candlelight?) Asexual reproduction does not require the reorganization of genetic materials, so can be accomplished simply by one cell dividing itself into two parts. This can occur in various ways as indicated below.

**Asexual reproductive Processes:**

1) **Binary fission** – During binary fission, one cell divides itself in half across the long axis, giving rise to two new daughter cells. Since most fungi form hyphae, fission does not necessarily involve physical separation of the cells present, but does involve **mitosis** (separation of the chromosomes).
2) **Budding** – Budding involves the uneven division of cytoplasm during the fission process, such that one daughter cell receives most of it, and the other (the bud) receives only a small amount (though both cells gain a full compliment of genetic material). If conditions are good, the bud grows until it reaches full size and separates, if not, the bud can be eliminated with little loss to the original cell. Asexual spores called **blastospores** are essentially buds (as are microconidia).
3) **Fragmentation** – Fragmentation can occur after fission has allowed the formation of numerous cells in multiple hypha. During fragmentation the hyphae break into little pieces or fragments, and each one has the potential of forming a new fungus. Asexual spores known as **arthrospores** and **chlamydospores** are essentially thick-walled fragments formed by the fragmentation of modified hyphae.
4) **Spore formation** (**sporulation**) – Asexual spores known as **sporangiospores** and **conidiospores** are formed at the ends of specialized hyphae (usually) and typically occur in large numbers as described below. Characteristics of asexual spores such as arrangement and color are often useful in fungus classification.
    a) **Sporangiospores** are contained within sac-like structures called **sporangia** (singular = **sporangium**) supported by hyphae called **sporangiophores**. These may be rounded or linear in shape as demonstrated by the *Rhizopus* and *Saprolegnia* observed in the laboratory. Some sporangia occur as sac-like pustules on the undersides of plant leaves, and are essentially formed by the plant epidermis (as demonstrated by *Albugo*).

b) **Conidiospores** are arranged like beads on a string at the ends of hyphae called **conidiophores**. Conidiospores are formed by specialized hyphae called **phialids** and arise through fission at the phialid tip. Older conidiospores are moved farther away from the phialid as new conidiospores form. The arrangement of phialids on conidiophores is variable and often useful in fungus classification.

**Sexual Reproductive Processes:**

Sexual reproduction requires the participation of two genetically dissimilar fungi (of the same species) and typically occurs in three stages or steps as outlined below:

1. **Plasmogamy** – Plasmogamy involves the joining of the protoplasm (plasma = protoplasm, gamous = union or marriage), and requires decomposition of the cell walls separating the hyphae involved.
2. **Karyogamy** – Karyogamy involves the joining of two haploid nuclei (karyon = nucleus) and results in the formation of a diploid cell called a **zygote**. **Haploid** cells/nuclei have only one set of chromosomes, while **diploid** cells/nuclei have two.
3. **Meiosis** – Meiosis (reduction division) is a process involving separation of chromosomes and the division of the diploid nucleus into two, haploid parts. An important feature of meiosis is the formation of new genetic combinations, not possible through asexual reproduction.

These stages may be separated in time, and organisms categorized as **dikaryotic** fungi typically form masses of hyphae carrying pairs of haploid nuclei after undergoing plasmogamy. These eventually undergo karyogamy and meiosis, but take their time about it. Though meiosis as it occurs in plants and animals has been thoroughly studied and appears to be fairly consistent, meiosis occurring in microorganisms is quite variable.

Fungi typically show no sexual dimorphism, i.e., lack structures recognized as male Vs female, so fungi engaging in sexual reproduction are often designated as plus (+) and minus (-) strains. During karyogamy, plus-type and minus-type haploid nuclei join and form a structure called a **diploid zygote**; however, because the DNA forming the chromosomes typically replicates prior to meiosis, the zygote is actually **tetraploid** (each X-shaped chromosome is made up of two chromatids, or two copies of the DNA present). During meiosis, chromosomes line up along the middle of the cell and are pulled apart by microtubules (the spindle apparatus). Typically there are two sets of cell divisions (chromosome separations) involved, with chromosomes lining up in pairs during the first set and chromosomes lining up in single file during the second. The recombination of genetic material resulting in genetic variation occurs during the first division cycle as chromosomes pair up and then separate. The chromosomes aligned in chromosome pairs often exchange segments and pairs separate randomly giving rise to different combinations. The formation of haploid cells or **gametes** occurs during the second division cycle as each chromosome is divided into two chromatids. Sexual reproduction results in the formation of haploid sexual spores designated as **oospores**, **zygospores**, **ascospores** or **basidiospores** depending on their source, arrangement and means of formation.

**Significance (importance) of fungi –** Fungi are significant to us and to other organisms in a variety of ways, some of which are listed below:

1) Many fungi are **saprotrophs** or decomposers that break down dead, decaying materials releasing nutrients into soils. Imagine what this world would be like if dead organic materials (wood, leaves, grass, etc.) did not break down. Although the random decomposition of organic materials is sometimes irritating/detrimental for humans, the benefits of this activity far outweigh the costs.
2) Many fungi form **mycorrhyzae** that aid forest trees and other plants with the uptake of minerals and water. In some forest regions the harvesting of mushrooms by humans has depleted the fungus populations so much that trees are dying.
3) Some fungi serve as a **food source** for other organisms including humans.
4) Various types of fungi are used in **food processing**, e.g., the production of cheese, beer, wine, bread, etc.
5) Some fungi are a source of **antibiotics** (e.g., Penicillins and Cephalosporins), chemicals used to control pathogenic bacteria inside the human body.
6) Many fungi form **enzymes** that can be used for industrial processes.
7) Many types of fungi produce **organic acids and solvents** as fermentation products and these have multiple uses. Some fungi form organic compounds equivalent to jet fuel.
8) Fungi can be genetically engineered to produce complex **proteins** originating in other organisms.
9) Some fungi are **pathogens** or disease-causing agents and some produce hallucinogenic substances such as LSD. Though these features are not beneficial to humans, they are still significant.

**Note** – Various types of bacteria are significant in all the ways listed for fungi, and in addition produce oxygen and methane. Bacteria are also being investigated as a source of hydrogen, and may be incorporated into computer technology.

**Medical Mycology:**

Although most fungi are saprotrophs and not damaging to other organisms, some fungi parasitize plants or animals, and some are pathogens responsible for disease symptoms. Some plant diseases caused by fungi include Dutch elm diseased, chestnut blight, potato blight, apple scab, peach leaf curl, corn smut, rusts and mildew. Since the majority of students taking this class are interested in the allied health fields, some medically significant fungi will be described in greater detail.

**Mycoses** – Mycoses (singular = mycosis) are fungal induced diseases occurring in humans and other animals. Though living standards have improved for many people, fungal infections remain a significant problem and the incidence of human mycoses has actually increased over time. In addition to the obvious increase in the human population, the increase in mycoses can be attributed to three major factors:

1) **Widespread use of antibiotics and other antimicrobial drugs.** These are used to control bacteria inside the human body, and when bacteria are eliminated the delicate balance between organisms categorized as normal flora is upset. Fungi gain access to more resources, grow rapidly and begin to cause damage to host cells and tissues.
2) **Increased use of chemotherapeutic agents** in the treatment of cancer and organ/tissue transplant patients. These cause can cause significant damage to immune cells.

3) **HIV infection** and damage to the immune system resulting in Acquired Immune Deficiency Syndrome (AIDS).

All of these factors weaken the immune system either by creating an imbalance in normal microbial populations or by damaging the host cells involved in defense. **The primary factor, determining if or not a person will be infected by fungi is the state of that individual's immune system.** If the immune system is functioning normally, fungal infection is unlikely, but if the immune system is damaged or weakened, any fungus can become a pathogen. Since fungi are abundant in the environment, this is a significant problem.

Fungal infections can be divided into categories based on what portions of the body are involved. For simplicity, we will divide the mycoses into three categories as follows:

1) **Superficial mycoses** – Superficial mycoses occur on the body surface and are caused by fungi infecting skin, hair and nails. These tend to be **chronic** (long term) and often cause considerable irritation, but are generally not life threatening. The fungi responsible for superficial mycoses are often called **dermatophytes** and include genera such as ***Epidermophyton***, ***Trichophyton*** and ***Microsporum***. Infection is not limited to humans and the symptoms caused by these fungi are often worse when the fungi are transmitted from non-human animals to people. Some commonly encountered superficial mycoses include:

   a) **Tinea pedis** or athlete's foot, caused by *Epidermophyton floccosum*
   b) **Tinea capitis** or ringworm of the scalp, caused by *Microsporum* or *Trichophyton*
   c) **Tinea corporis** or ringworm of the body, caused by *Microsporum gypseum* or *Trichophyton* species.

   Fungal infections commonly called ringworm were named for the puffy, red-colored, ring-like lesions formed on the skin surface. These are caused by fungal waste products irritating to the skin, but were once believed to be formed by worm-like organisms living under the skin. Because dermatophyte fungi are widespread and produce numerous, tiny, asexual spores, these are often present on gym floors and pool decks, in locker rooms and laundry facilities and sometimes in other locations frequented by humans.

2) **Subcutaneous mycoses** – Subcutaneous mycoses involve damage to the tissue layers located just below the skin and typically appear as small, wart-like bumps on the skin surface. The fungi involved are usually organisms found in soil or vegetation, introduced by a puncture, scratch, cut, or other wound. Though usually limited by immune mechanisms, superficial mycoses can sometimes spread along lymphatic ducts and result in more severe tissue damage. They are rarely if ever life threatening. Two types of commonly encountered superficial mycoses include:

   a) **Sporotrichosis** – Sporotrichosis is caused by fungi identified as ***Sporotrix schenckii***, and typically occurs in persons working with plants, sphagnum moss or hay. Sometimes referred to as "rose-thorn disease", sporotrichosis typically involves lesions on the hands, arms or feet as the result of contact with thorns, pine needles,

twigs or wire. Over time the wart-like bumps may become painful, boil-like lesions eventually forming open sores that are slow to heal.

b) **Chromomycosis** – Chromomycosis (chromoblastomycosis) is named for the dark-colored lesions associated with infection involving various different types of black molds (dematiaceous fungi). This type of infection is often chronic, but not life-threatening.

3) **Deep or systemic mycoses** – Deep or systemic mycoses involve fungi that enter deep tissues (heart, liver, brain, etc.) by becoming associated with the lymphatic and/or cardiovascular systems and traveling throughout the body. These fungi typically enter their host through the respiratory system as spores are breathed in. They can cause influenza or pneumonia-like symptoms initially, but if not controlled by immune mechanisms can spread into the circulatory system and cause damage throughout the body

a) **Coccidioidmycosis** – Coccicioidomycosis (also called desert rheumatism, valley fever or San Joaquin Valley fever), is caused by a type of soil fungus identified as ***Coccidioides immitis.*** These fungi occur abundantly in certain regions including the American Southwest and in the southern portion of California's central valley. **Arthrospores** (fragments of hyphae) produced by these fungi are abundant in certain soils and can readily be picked up and transported by the wind. Most people exposed to arthrospores are asymptomatic, i.e., experience no disease symptoms, but flu-like symptoms occur in some individuals. Between 1 and 10% of those experiencing flu-like symptoms later develop a red rash indicative of an allergic or hypersensitivity reaction, and this is sometimes accompanied by joint pain. In persons with poor immune function, the fungus is not controlled, and spreads throughout the body causing lesions in various organs potentially resulting in death. Coccidioidomycosis is usually restricted to specific regions where the fungus is prevalent in soil, but during the drought years of 1977, winds carried soil particles and fungus spores as far north as SanFrancisco. A number of cases were also reported in the Los Angeles area following the Northridge earthquake of 1994.

b) **Histoplasmosis** – Histoplasmosis is caused by a type of fungus identified as ***Histoplasma capsulatum.*** These fungi prefer soils rich in nitrogen, so are often abundant in areas containing bat and/or bird droppings. People frequenting caves (spelunkers) and those working in guano mines are at high risk of developing histoplasmosis. Fungus spores are breathed in, and the resulting infections cause varying degrees of respiratory damage. Some individuals experience chest pain and a dry cough, some develop pneumonia-like symptoms and some develop chronic, tuberculosis-like infections resulting in tissue damage and scarring. If not controlled by the immune system, these fungi can enter the bloodstream, become widely disseminated, and cause potentially fatal lesions throughout the body.

**Fungi as Opportunistic Pathogens**

Fungi not usually associated with disease, but able to cause disease symptoms under certain circumstances are referred to as **opportunistic pathogens**, and the diseases they cause are called **opportunistic mycoses**. Some of the fungi involved are part of our "normal flora", i.e., organisms normally found living in or on the human body, but many

are fungi common to soil and vegetation. Opportunistic mycoses occur in individuals with compromised immune function, and for these individuals, virtually any fungus is a potential pathogen. Some fungi frequently associated with opportunistic mycoses are listed below:

a) ***Candida albicans*** – *Candida* is a type of yeast-like fungus commonly encountered as an inhabitant of the human body (forms part of our normal flora). *Candida* populations are usually kept in check by bacteria competing with them for space and nutrients. When bacteria populations are reduced, as occurs during treatments involving antibiotics, these fungi can reproduce rapidly and cause tissue damage resulting in disease symptoms. *Candida* is commonly associated with thrush (in the mouth), vaginal and eye infections, but in severely immunocompromised individuals this fungus can cause potentially fatal septicemia (infection in the bloodstream resulting in disease symptoms).

b) ***Cryptococcus neoformans*** – *Cryptococcus* is a type of yeast-like fungus commonly associated with bird droppings. Spores from this fungus gain access to the body through the respiratory system, enter the bloodstream and migrate to brain where they can cause a potentially fatal form of meningitis. *Cryptococcus*, like *Candida*, is most dangerous to severely immunocompromised individuals.

c) ***Aspergillus fumigatus*** – Fungi in the genus *Aspergillus* including *A. fumigatus*, *A. niger* and others, are commonly associated with lung infections in immunocompromised individuals. The conidiospores formed by these fungi are small, readily air-borne and easily breathed in. Various species of *Aspergillus* have also been found to cause deep or systemic mycoses when introduced through severe tissue trauma associated with lawn mower and chain saw accidents.

d) ***Rhizopus stolonifera*** – Though rarely considered as pathogenic, *Rhizopus stolonifer* and other species can sometimes form fungus balls in lung tissue. They enter the lungs through respiration and because they are aerobic, find the environment well suited to their growth. Fungus balls typically occur in lung tissue damaged by prior infection/conditions and in individuals lacking normal immune function.

e) ***Pneumocystis carinii*** – Fungi in the genus *Pneumocystis* are opportunistic pathogens commonly associated with pneumonia in AIDS patients (*Pneumocystis carinii* pneumonia or PCP). Previously categorized as protozoa, these fungi initially cause symptoms including dry cough, fever and breathing difficulty. If left untreated they can cause potentially fatal pneumonia.

**Mycotoxins and Intoxication**

Various types of fungi produce toxic substances collectively referred to as **mycotoxins** (mycotoxins = toxic substances produced by fungi). Ingestion of fungus toxins can cause **intoxication** (poisoning due to ingestion of toxic substances) sometimes resulting in reduced liver function, hallucination or death depending on the type of fungus involved. Some examples of fungi known to produce mycotoxins are listed below.

a) ***Amanita phalloides*** – *Amanita phalloides* is a type of fleshy fungus often found growing in damp wooded areas. This and other species within the *Amanita* genus produce potent mycotoxins known to cause severe liver damage and sometimes death when ingested. Although some species of *Amanita* are brightly colored and easily avoided, others are not, and intoxication due to ingestion of *Amanita* occurs with surprising frequency.
b) ***Aspergillus flavus*** – *Aspergillus flavus* is a type of mold known to produce a potent mycotoxin called **Aflatoxin** (A = Aspergillus, fla = flavus, toxin). Fungi in the genus *Aspergillus* are very common in the environment, growing in association with soil and vegetation, and Aflatoxin is often found in association with grain products and peanuts. Aflatoxin is one of the most potent carcinogens (cancer-causing agents) known to man, and ingestion of foods contaminated with it can result in sever liver damage.
c) ***Claviceps purpura*** – *Claviceps purpura* is a type of mold commonly associated with rye grain and responsible for causing a condition called ergot. These fungi also produce hallucinogenic toxins (lysergic acid derivatives = LSD) which when ingested can cause convulsive ergotism and hallucination. The consumption of bread made with fungus-infected rye grain, and the resulting hallucination has been implicated as a major factor influencing witnesses involved in the Salem Witch Trials of the 1600s.
d) ***Stachybotrys atra*** – *Stachybotrys atra* is a type of fungus sometimes referred to as black mold, and commonly found growing on surfaces rich in cellulose (e.g., wood, dead leaves and the paper backing of wall board). Detection of *Stachybotrys* inside buildings wetted by leaky roofs, flooding or plumbing problems is problematic because exposure to this fungus can cause health problems. Spores produced by *Stachybotrys* can cause hemorrhaging in infant lungs, and inhalation of air-borne toxins has been reported to cause headache, dizziness and reduced immune function.

Note – In addition to being pathogenic and producers of toxins, many fungi release spores that are among the leading causes of **atopic allergy** (hay fever) in humans.