

Chapter 31 Fungi

I. What are the fungi?

- A. Fungi are master decomposers—the only organisms that can break down wood completely.
- B. Fungi absorb carbon and energy from other organisms.
 - 1. Many fungi digest dead tissues of plants and serve as decomposers.
 - 2. Others are parasites that digest living tissues of plants.
 - 3. Some plant/fungal relationships are mutually beneficial.
 - a. Fungi provide nitrogen and phosphorus to the plant.
 - b. Plant provides sugars and other reduced-carbon compounds to the fungus.

II. Why Do Biologists Study Fungi?

- A. Fungi feed the land plants that feed us.
 - 1. Mycorrhizal fungi live in close association with plant roots.
 - 2. Without these fungi, plant growth slows; therefore, these fungi are important to agricultural productivity. (Fig. 31.1)
- B. Fungi Speed the Carbon Cycle on Land
 - 1. The fossil record illustrates the importance of fungi to Earth.
 - a. Little to no fossilized fungi found in the coal of the Carboniferous period.
 - (1) This lack of saprophytic fungi is probably responsible for the large deposits of dead plant tissue (peat) during that period.
 - (2) Biologists hypothesize that because peatlands have an acidic pH, the fungi could not grow in them.
 - (3) Because the fungi could not grow and decompose the peat, coal formed as the peat was exposed to heat and pressure.
 - b. A large spike in the presence of fungal fossils coincides with the mass extinction event of the Permian period. (Fig. 31.2)
 - (1) Biologists hypothesize that the end-Permian extinction involved a massive die-off of land plants and marine organisms.
 - (2) This die-off produced a massive amount of rotting wood and allowed a population explosion of saprophytic fungi.
 - 2. Saprophytic (decomposing) fungi are important in today's terrestrial environment. (Fig. 31.3)
 - a. The two basic components of the carbon cycle:
 - (1) The fixation of carbon by land plants
 - (2) The release of carbon dioxide from plants, animals, and fungi via cellular respiration
 - b. Fungi connect these two components of the carbon cycle.
 - (1) Fungi liberate the carbon from wood and recycle it into glucose and carbon dioxide.
 - (2) Without fungi, carbon would be trapped in the wood of trees and shrubs for a very long time, and terrestrial environments would be far less productive.
- C. Parasitic fungi cause animal and plant diseases.
 - 1. While fungi do cause some human diseases, most fungi are helpful to humans.
 - a. Athlete's foot, diaper rash, vaginitis, pneumonia, and thrush are all caused by human fungal infections.
 - b. Soil-dwelling fungi have been the source for many important antibiotics.
 - 2. The most destructive impact that fungi have on us is through our food supply. (Fig. 31.4)
 - a. Fungi destroy millions of dollars worth of crops each year.
 - b. Fungi have destroyed significant numbers of trees in North America.
 - (1) Chestnuts and elms have fallen prey to imported fungal species.

- (2) This epidemic changed the composition of the upland and floodplain forests of the eastern U.S., areas that used to be dominated by chestnut and elm trees.

III. How Do Biologists Study Fungi?

A. Analyzing Morphological Traits

1. What does a fungus look like?
 - a. Each fungal species grows in one of two forms:
 - (1) Single-celled yeast (**Fig. 31.5a**)
 - (2) Multicellular, filamentous mycelia (**Fig. 31.5b**)
 - b. Yeasts are small and easy to grow in the laboratory, so they have been important model organisms in biology.
2. The nature of the fungal mycelium
 - a. Mycelia are dynamic.
 - (1) They grow in the direction of food sources, and die back when food is scarce.
 - (2) Therefore, a fungus's body shape is constantly changing.
 - b. Mycelia are made up of individual filaments called hyphae.
 - (1) A hypha is haploid.
 - (2) A hypha is a long, narrow tube that branches frequently. (**Fig. 31.6a**)
 - (3) Each hypha is broken down into cell-like compartments that are divided by an incomplete wall, called a septum. (**Fig. 31.6b**)
 - (a) Pores within the septa allow for the flow of cytoplasm, organelles, and other material between compartments.
 - (b) Due to this flow, fungal mycelia are intermediates between multicellular organisms and a large unicellular organism.
 - (c) Some hyphae are coenocytic, lacking septa and having continuous cytoplasm throughout the entire mycelium.
 - c. The shape of mycelia gives fungi the highest surface-to-volume ratio among multicellular organisms.
 - (1) This is important because fungi make their living via absorption.
 - (2) However, the down side to this large surface-to-volume ratio is the tendency of fungi to dry out. For this reason, fungi live in moist environments.
3. Reproductive structures
 - a. Thick, fleshy structures on multicellular fungus are reproductive structures.
 - (1) These are the only structures exposed to the air, and they do not absorb food (even though they arise from mycelia and have hyphae).
 - (2) Mushrooms are the classic examples of such structures.
 - b. Fungi can be divided into four groups, based on their unique reproductive structures.
 - (1) Chytridiomycota live in water and are the only fungi with motile cells. (**Fig. 31.7a**)
 - (a) Spores produced by asexual reproduction have flagella.
 - (b) Gametes produced by sexual reproduction have flagella.
 - (2) The haploid hyphae of Zygomycota come in different mating types and yoke together during sexual reproduction. (**Fig. 31.7b**)
 - (a) A mating type is determined by the presence of certain alleles of mating genes.
 - (b) Chemical messengers released by the hyphae indicate their mating type.
 - (c) Two hyphae will become yoked together if they are of different mating types, and will fuse to form a zygote.
 - (3) Basidiomycota or club fungi form spores in basidia. (**Fig. 31.7c**)
 - (a) These fungi use mushrooms, bracket fungi, and puffballs to reproduce.
 - (b) Inside these structures, little pedestals called basidia form at the end of hyphae and form spores.
 - (4) Sac fungi, or Ascomycota, produce asci. (**Fig. 31.7d**)
 - (a) The tips of the hyphae produce distinctive sac-like cells called asci.
 - (b) An ascus contains haploid spores.

B. Evaluating Molecular Phylogenies

1. How are these four major groups related?
 - a. Biologists hypothesized that each major group, as defined by reproductive structure, represents a monophyletic group. (Fig. 31.8a)
 - b. Based on the following assumptions, scientists hypothesized that chytrids were the most basal group.
 - (1) Fungi evolved from aquatic protists.
 - (2) Fungi moved to land coincidentally with plants.
 - c. To test these hypotheses, biologists sequenced genes that code for the rRNA in the small ribosomal subunit from a variety of fungi.
 - (1) The results were used to estimate fungal phylogeny.
 - (2) The results confirmed that two of the groups are monophyletic (ascomycetes and basidiomycetes).
 - (3) The data conflicted with the claim of monophyly for chytrids and zygomycetes.
 - (a) A lineage of chytrids is likely the basal group of fungi that evolved.
 - (b) Chytridiomycota and Zygomycota appear to be paraphyletic.
 - (c) Swimming gametes and yolked hyphae are interspersed throughout the basal branches of the tree, implying that these structures evolved more than once, or both were present in a common ancestor.
2. Where do fungi belong on the tree of life? (Fig. 31.9)
 - a. DNA sequence analysis has led researchers to conclude that:
 - (1) The closest living relatives to fungi are microsporidians.
 - (a) Microsporidians cause serious disease in AIDS patients.
 - (b) The discovery of their relationship to fungi may indicate that fungicides may be effective treatment for such infections.
 - (2) Fungi are more closely related to animals than to plants.
 - (a) A lot of animals and fungi make chitin.
 - (b) Flagella structure in animals and fungi is similar.
 - (c) Both animals and fungi store food as glycogen.

C. Experimental Studies of Mutualism

1. Biologists hypothesize that the evolution of plant-fungal symbiosis has played a significant role in the diversification of fungi.
 - a. Plant-fungal symbiosis can be either mutualistic (both benefit), parasitic (one benefits, one is harmed) or commensalistic (one benefits, the other is unaffected).
 - b. How do biologists study these relationships?
 - (1) Cataloging the species of fungus and where it lives in/on the plant via light or electron microscopy.
 - (2) Presence/absence experiments in which plants are grown with and without their symbiotic fungus.
 - (3) Radioactive isotope experiments in which the mutualistic relationship is defined by observing the transfer of nutrients from plant to fungus, and vice versa. (Fig. 31.10)
 - (a) Plants provide sugars to the fungi.
 - (b) Fungi provide nitrogen, phosphorus, and carbon to the plant.

IV. What Themes Occur in the Diversification of Fungi?

A. Fungi participate in several types of mutualism.

1. Ectomycorrhizal fungi (EMF)
 - a. Mycelia form a dense network of hyphae (0.1 mm thick) around plant roots. (Fig. 31.11a)
 - (1) Hyphae extend between the cells of the outer layer of the root.
 - (2) Hyphae also extend into the soil.
 - b. Are found on virtually all tree species in temperate and boreal forests
 - c. Are often members of the Basidiomycota
 - d. Are abundant in cold, northern habitats that have short growing seasons

- (1) Decomposition of needles, leaves, twigs, trunks is very slow.
 - (2) Nitrogen remains tied up in dead tissues.
 - (3) EMF secrete peptidases that break bonds between amino acids.
 - (4) EMF absorb the released nitrogen and transport it close to tree roots.
 - (5) Tree roots take up the nitrogen and secrete sugars and other reduced-carbon compounds that the EMF uses.
 - e. Researchers tested the importance of EMF to plant growth.
 - (1) Birch seedlings grown in forest soil in pots without EMF could not acquire nitrogen.
 - (2) Conclusions: EMF are the "dominant nutrient-gathering organs in most temperate forest ecosystems."
2. Arbuscular mycorrhizal fungi (AMF) or endomycorrhizal fungi
 - a. Grow into the cells of the plant root tissue (**Fig. 31.11b**)
 - b. The hyphae branch extensively (*arbuscular* means "little tree")
 - (1) AMF directly contact the plasma membrane of root cells.
 - (2) The highly branched hyphae increase the absorptive surface area of the fungus and its host.
 - (3) AMF form a pipeline from the soil to the root.
 - c. Are members of the Zygomycota, the Glomales lineage.
 - d. Occur in 80% of all land plant species, particularly in plants of grasslands and warm or tropical forests
 - e. AMF were proposed to deliver phosphorus to plants, not nitrogen.
 - (1) Grasslands and warm or tropical forests have long growing seasons.
 - (2) Plant tissues degrade rapidly, so nitrogen is not limiting.
 - (3) In these climates, phosphorus is in greatest demand.
 - (4) Radioactive phosphorus was used to demonstrate that AMF deliver phosphorus to their host plants.
 3. Are endophytes mutualistic?
 - a. Endophytes are fungi that live in the aboveground tissues of a plant.
 - b. Endophytes do not cause disease in the tissues they invade, so they are not parasitic.
 - c. To test the hypothesis that endophytes are mutualistic, biologists used presence/absence experiments in grasses.
 - (1) Grasses grown in the absence of endophytes are more susceptible to disease.
 - (2) Endophytic fungi produce chemicals that deter or kill insect herbivores.
 - (3) Endophytes are thought to get nutrients from the plant.
 - (4) Conclusion: Endophytes and plants do have a mutualistic relationship.
 - d. Similar experiments in trees showed no benefit to the trees in the presence of endophytes, leading biologists to conclude that some endophytes may be commensalistic.
- B. Adaptations That Make Fungi Effective Decomposers (Fig. 31.12)**
1. Extracellular digestion
 - a. Large molecules such as starch, cellulose, and lignin cannot diffuse across the membranes of hyphae.
 - b. Therefore, fungi secrete digestive enzymes outside their hyphae into their food, so digestion actually occurs extracellularly.
 - c. The smaller, digested compounds can then be absorbed by the hyphae.
 2. Lignin degradation
 - a. Lignin is a family of strong polymers that give the woody texture to plant stems.
 - b. Members of the Basidiomycetes are the only organisms that can degrade lignin completely to CO₂.
 - c. Commercial Impact
 - (1) Soft, absorbent paper can be made only by digesting lignin without using caustic chemicals.
 - (2) Cleanup of waste from sawmills and paper mills also requires the ability to degrade lignin using noncaustic chemicals.
 - d. Biologists studied fungi to determine how they digest lignin.

- (1) Molecules that fungi secrete into their extracellular space were purified and tested for the ability to degrade lignin.
 - (2) An enzyme, lignin peroxidase, was found.
 - (a) The enzyme catalyzes the oxidation of an atom in the aromatic rings of lignin.
 - (b) The removal of the single electron leaves a free radical.
 - (c) The extremely unstable free radicals trigger a series of uncontrolled and unpredictable reactions.
 - (d) Lignin is split into small subunits.
 - (e) The digestion process has been described as "enzymatic combustion," analogous to the uncontrolled reactions that occur when gasoline burns in a car engine.
 - e. Lack of specificity in the lignin degradation process is based on the heterogeneity of the lignin molecule.
 - (1) Lignin is extremely diverse—over ten different types of linkages occur in the polymer.
 - (a) No single enzyme could cleave all these different linkages.
 - (b) Once the free radical forms, all the different linkages can be broken.
 - (2) The degradation of lignin cannot be harnessed to drive ATP synthesis.
 - (a) Potential energy is lost during lignin breakdown in large, unpredictable jumps.
 - (b) Fungi cannot grow on lignin as their sole carbon source, because its breakdown cannot be used to yield ATP.
 - f. Why do fungi break down lignin if they cannot use it as a carbon or energy source?
 - (1) Lignin forms a dense matrix around the cellulose fibers in wood.
 - (2) Degrading lignin gives fungi access to energy-rich cellulose.
3. Digesting cellulose
- a. Only a handful of organisms on Earth can digest cellulose.
 - b. These organisms produce cellulases (cellulose-digesting enzymes).
 - c. Cellulases are extremely specific in their action.
 - d. The seven cellulase enzymes of the fungus *Trichoderma reesei*
 - (1) Two cellulases catalyze the breakdown of cellulose into the disaccharide cellobiose.
 - (2) The other cellulases are also specific and catalyze other hydrolysis reactions.
 - (3) The seven enzymes together result in total breakdown of long cellulose polymers to energy-rich glucose monomers.
- C. Variation in Life Cycles
1. Basic aspects of fungal life cycles
 - a. Fungi produce spores by both asexual and sexual reproduction.
 - (1) Spores are the dispersal stage in the fungal life cycle.
 - (2) Fungi produce spores in large numbers.
 - b. If a spore falls on a food source, it will germinate and form a mycelium.
 - c. If food becomes scarce, a fungus will reproduce to form spores that will be dispersed by water, wind, or animals.
 - d. Scientists hypothesize that spore production allows starving mycelia to disperse offspring to new habitats with more food.
 2. Unique aspects of fungal life cycles
 - a. Chytridiomycota are the only fungi that produce gametes, and they are not different enough from one another to call them sperm and egg.
 - b. Fertilization in fungi occurs in two distinct steps.
 - (1) Fusion of cells (plasmogamy) (**Fig. 31.13a**)
 - (2) The nuclei from these fused cells can divide and grow independently (heterokaryotic).
 - (3) At some point during mycelium development, a pair of unlike nuclei fuses to form a diploid zygote (karyogamy).
 - c. Some fungi reproduce only asexually and are called molds.
 - d. Among sexually reproducing species of fungi, the nature of the heterokaryotic stage and the morphology of the spore-producing structure vary.
 - (1) Chytridiomycota exhibit alternation of generations. (**Fig. 31.13b**)
 - (a) Swimming gametes are produced in haploid adults by mitosis.

- (b) Gametes fuse to form a diploid zygote that grows into a sporophyte.
- (c) Meiosis occurs in the sporangium (a structure in the sporophyte), forming spores that are dispersed.
- (2) In Zygomycota, sexual reproduction involves the fusion of two hyphae. (Fig. 31.13c)
 - (a) Plasmogamy forms a zygote, and is followed by karyogamy.
 - (b) Zygotes are encased in a tough coating and can persist until conditions are favorable for growth.
 - (c) At that time, meiosis occurs, and spores are produced.
- (3) Basidiomycota form mushrooms, bracket fungi, and puffballs. (Fig. 31.13d)
 - (a) All of these structures originate from heterokaryotic hyphae.
 - (b) These structures have spore-producing basidia at hyphae tips in which karyogamy occurs.
 - (c) The diploid nucleus undergoes meiosis, and haploid spores are produced.
 - (d) Spores are expelled from the tip of the basidia.
- (4) In Ascomycota, hyphae of different mating types fuse. (Fig. 31.13e)
 - (a) A heterokaryotic hypha emerges, grows into a structure whose hyphae have sac-like spore-producing structures called asci.
 - (b) Karyogamy occurs in the ascus, followed by meiosis that forms haploid spores.
 - (c) Spores are forcibly ejected and dispersed by the wind.

V. Key Lineages of Fungi (Fig. 31.14)

A. Chytridiomycota (Chytrids) (Fig. 31.15)

- 1. Absorptive lifestyle:
 - a. Some species have cellulases and are decomposers.
 - b. Many freshwater species are parasitic.
 - c. Mutualistic chytrids live in the guts of cows, elk, and other herbivores.
- 2. Life cycle:
 - a. Produce flagellated spores via asexual reproduction.
 - b. A few species reproduce sexually and exhibit alternation of generations.
- 3. Human and ecological impacts:
 - a. Epidemic chytrid infections have occurred in frog populations. (Essay, Fig. 31.15)
 - b. Important decomposers of wet soil in lakes and ponds.

B. Zygomycota

- 1. Mucorales and other basal lineages (Fig. 31.17)
 - a. Absorptive lifestyle:
 - (1) Many species are saprophytes that live on plant debris.
 - (2) Some are insect parasites.
 - (3) Others are predatory and trap their microscopic prey in a sticky substance in their cell walls, or in looped hyphae.
 - b. Life cycle:
 - (1) Asexual reproduction is common.
 - (2) Hyphae of different mating types fuse during sexual reproduction.
 - c. Human and ecological impacts:
 - (1) The common black bread mold, *Rhizopus stolonifer*, is a common household pest.
 - (2) Some saprophytic species cause large losses to the fruit and vegetable industry.
 - (3) Some *Mucor* species are used to make steroids for medical use.
- 2. Glomeromycota (Fig. 31.18)
 - a. Absorptive lifestyle:
 - (1) All AMF species are members of Glomeromycota.
 - (2) These species absorb phosphorus and nitrogen from the soil and transfer them to their plant host.
 - (3) They absorb sugars and other nutrients from the plant.
 - b. Life cycle: Most form spores underground.

- c. Human and ecological impacts: Important to the growth and productivity of grasslands and tropical forests.
- C. Basidiomycota (Club fungi) (Fig. 31.19)
- 1. Absorptive lifestyle:
 - a. Important saprophytes; the only species that can completely digest wood
 - b. Some species form ectomycorrhizal relationships with trees in temperate forests.
 - c. Some are parasitic; rusts and smut fungi.
 - 2. Life cycle:
 - a. Asexual reproduction through the production of spores, or through the fragmentation of mycelia
 - b. Sexual reproduction involves the production of basidia.
 - c. Sometimes basidia are housed in mushrooms, brackets or puffballs.
 - 3. Human and ecological impacts:
 - a. EMF are important for forest management.
 - b. Mushrooms are a source of food.
 - c. Mushroom toxins are used in medical and biological research.
- D. Ascomycota (Sac fungi)
- 1. Lichen-formers (Fig. 31.20)
 - a. Absorptive lifestyle:
 - (1) These species live in association with cyanobacteria and single-cell green algae to form lichen.
 - (2) The fungi seem to protect the photosynthetic cells.
 - (3) The photosynthetic cells provide sugars for the fungus.
 - b. Life cycle:
 - (1) Lichens reproduce sexually via soredia that contain both participants.
 - (2) The fungal partner may form spores in asci.
 - c. Human and ecological impacts:
 - (1) Lichens dominate the arctic and Antarctic tundra.
 - (2) The major food for caribou.
 - (3) Rock-dwelling lichens break off mineral particles as they grow, initiating soil formation.
 - (4) Lichens are processed in perfume production.
 - 2. Non-lichen-formers (Fig. 31.21)
 - a. Absorptive lifestyle:
 - (1) Some species are EMF that associate with tree roots.
 - (2) Are the most common endophytic fungi.
 - (3) Some are saprophytic in forest floors and grasslands.
 - (4) Some are parasitic.
 - b. Life cycle:
 - (1) The aboveground reproductive structure containing asci is called an ascocarp.
 - (2) Therefore, these species are called cup fungi.
 - (3) Can also reproduce asexually by producing spores in conidia.
 - c. Human and ecological impacts:
 - (1) Some saprophytic species can grow on jet fuel or paint and can be used to clean up contamination.
 - (2) *Penicillium* is an important source for antibiotics.
 - (3) *Aspergillus* is an important source for citric acid used to flavor soft drinks.
 - (4) Some parasitic species can infect humans, other animals, and plants.