CHAPTER 19

Fungi



Unlike the wintergreen plant in the foreground, the painted suillus and Clitocybe aurantica *(inset), which are members of the kingdom Fungi, do not perform photosynthesis.*

Imagine forms of life that are found nearly everywhere on Earth yet seem poorly suited for the type of lifestyle that exists on our planet. These organisms usually cannot move from place to place. They do not perform photosynthesis, nor do they get their food by capturing other organisms. Instead, these organisms grow on their food source, digest the food outside their bodies, and then absorb it.

Despite their apparent limitations, these organisms are so common that it is virtually impossible to obtain a sample of soil that does not contain them. These unique life forms are fungi, and their world, as different as it may seem from ours, affects us every day. In this chapter, you will examine some of the characteristics of fungi and discover just what role they play in our environment.

CHAPTER OUTLINE

19–1 The Fungi
- Characteristics of Fungi
- Oomycota—Protistlike Fungi
- Zygomycota—Common Molds
- Ascomycota—Sac Fungi
- Basidiomycota—Club Fungi
- Deuteromycota—Imperfect Fungi

19–2 Fungi in Nature
- Ecological Significance
- Symbiotic Relationships
- Fungi and Human Life
- Diseases Caused by Fungi

19–1 The Fungi

Section Objectives

- Describe the structure of a typical fungus.
- Explain how fungi obtain food.
- Identify the five phyla of fungi.
- Summarize the methods of reproduction in fungi.

For many of us, the most common encounters with **fungi** (FUHN-jigh; singular: fungus) are unwanted ones: molds spoil our fruits and breads, mildew weakens our fabrics, and athlete's foot attacks our skin. In tropical areas, more than 50 percent of the food that is produced is spoiled by fungi before it can be eaten. And in temperate regions, trees such as the elm die of a fungal disease known as Dutch elm disease.

For reasons such as these, when we think of fungi, we think of death and decay. Fungi, however, are among the most interesting organisms in the living world. Not only do they help shape the natural environment, they also provide us with food —and in so doing, they display some remarkable and exotic lifestyles.

Characteristics of Fungi

Fungi are eukaryotic heterotrophs. You will recall from Chapter 17 that heterotrophs depend on other organisms for food. Many fungi are saprophytes, or organisms that obtain food from decaying organic matter. Others are parasites, which are organisms that live directly on the body of a plant or animal host and in so doing harm that organism. Still other fungi are symbionts, or organisms that live in close association with an organism of another species.



Figure 19–1 *All fungi are heterotrophs, or organisms that obtain food from organic compounds of other organisms. Many of these heterotrophs, such as the bracket fungi shown here, live as saprophytes, decomposing dead matter such as this tree.*

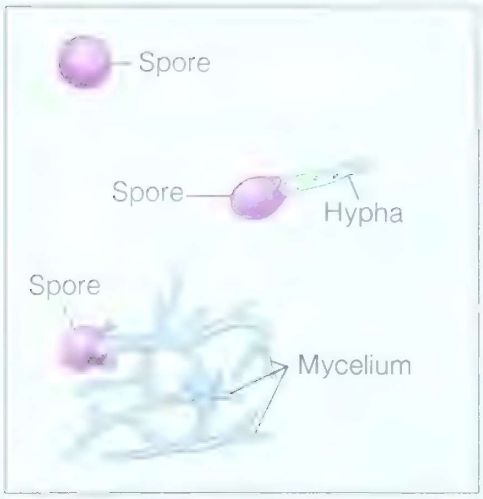
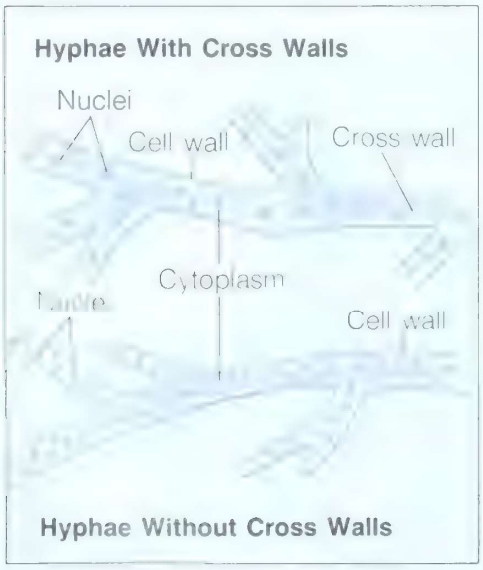


Figure 19–2 *A fungus develops from a spore that grows into a threadlike hypha. The hypha grows rapidly and branches until it resembles a tangled mass of threads called a mycelium.*

Figure 19–3 *Some hyphae are divided by cross walls that contain one or more nuclei. Other hyphae are coenocytic, meaning they lack cross walls.*



Fungi do not ingest their food. Instead, they absorb it through their cell walls and cell membranes. Fungi release digestive enzymes into their environment. The enzymes break down leaves, fruit, or other organic material into simple molecules, which then diffuse across the cell walls and cell membranes. This method of obtaining food makes fungi very important in nature: They produce powerful digestive enzymes that speed the breakdown of dead organisms, helping to recycle nutrients and essential chemicals. Together with the bacteria, fungi are the major **decomposers,** or organisms of decay.

Except for yeasts, which are unicellular, the body of a typical fungus is made up of many tiny filaments tangled together into a thick mass called a **mycelium** (migh-SEE-lee-uhm). The individual filaments are called **hyphae** (HIGH-fee; singular: hypha). In many fungi, the hyphae are divided by cross walls into cells containing one or more nuclei. See Figure 19–3. The cell walls of most hyphae are made up of chitin, a complex carbohydrate that is also found in the external skeleton of insects. The cell walls of other hyphae contain cellulose, the complex carbohydrate that makes up the cell walls in plants. The mycelium, or tangled mass of hyphae, is well suited to absorbing food because it permits a larger surface area to come in contact with the food source.

Most fungi reproduce both asexually and sexually. Asexual reproduction occurs either by the production of spores or by the fragmentation of the hyphae (each fragment becomes a new fungus). In some fungi, spores are produced in structures called **sporangia** (spoh-RAN-jee-uh; singular: sporangium). Sporangia are found at the tops of specialized hyphae called **sporangiophores.**

In many fungi, sexual reproduction involves two different mating types. One mating type is referred to as + (plus) and the other is referred to as − (minus). When the hyphae of opposite mating types meet, each hypha forms a **gametangium** (gam-uh-TAN-jee-uhm), or gamete-forming structure. Then the two gametangia fuse, and some of the nuclei pair and join to form zygote nuclei.

During the greater part of their life cycle, the nuclei of most fungi are haploid (N). Diploid (2N) nuclei form during sexual reproduction. Shortly after the nuclei fuse, meiosis (reduction division) occurs and produces haploid nuclei that dominate the remainder of the life cycle of fungi.

Fungi are classified according to their methods of reproduction and their basic structure. At one time fungi were classified either in the kingdom Plantae or in the kingdom Protista. Today, fungi are placed in their own kingdom, the Fungi.

We have divided the kingdom Fungi into five phyla: Oomycota, Zygomycota, Ascomycota, Basidiomycota, and Deuteromycota. Notice that the name of each phylum ends in *-mycota.* This suffix is derived from the Greek word for mushroom, which is *mykes. Mykes* is also the root for mycelium.

Oomycota—Protistlike Fungi

Because the fungi in the phylum Oomycota (oh-uh-migh-KOHT-uh) are so closely related to the plantlike protists, many scientists include them as one of the phyla within the kingdom Protista. Members of this phylum, called oomycetes, commonly form a white fuzz on aquarium fish or on organic matter sitting in water. Despite the phylum's common name of water molds, a few oomycetes are able to grow on land, but only under damp, humid conditions. Although these fungi are not common on land, they do cause a number of serious diseases among crop plants, including potato blight. We will consider these diseases when we examine how fungi fit into the environment.

The cell walls of oomycetes are made of cellulose. It is through these thin cell walls that the water molds absorb food. Oomycetes are the only fungi that produce motile spores. These spores swim through water and raindrops to new sources of food. The hyphae of oomycetes lack cross walls. As a result, the hyphae are multinucleate (have many nuclei).

The life cycle of a water mold is shown in Figure 19–4. Notice the two types of reproduction that can occur: asexual and sexual. In asexual reproduction, portions of the hyphae develop into sporangia (spore cases). Each sporangium produces flagellated spores that swim away from the sporangium in search of food. When food is found, the spores develop into hyphae, which grow into new organisms.

Figure 19–4 *The water mold, an oomycete, reproduces both asexually and sexually. During asexual reproduction, flagellated spores are produced by the diploid (2N) mycelium. These spores grow into new mycelia. During sexual reproduction, the male gamete fuses with the female gamete.*

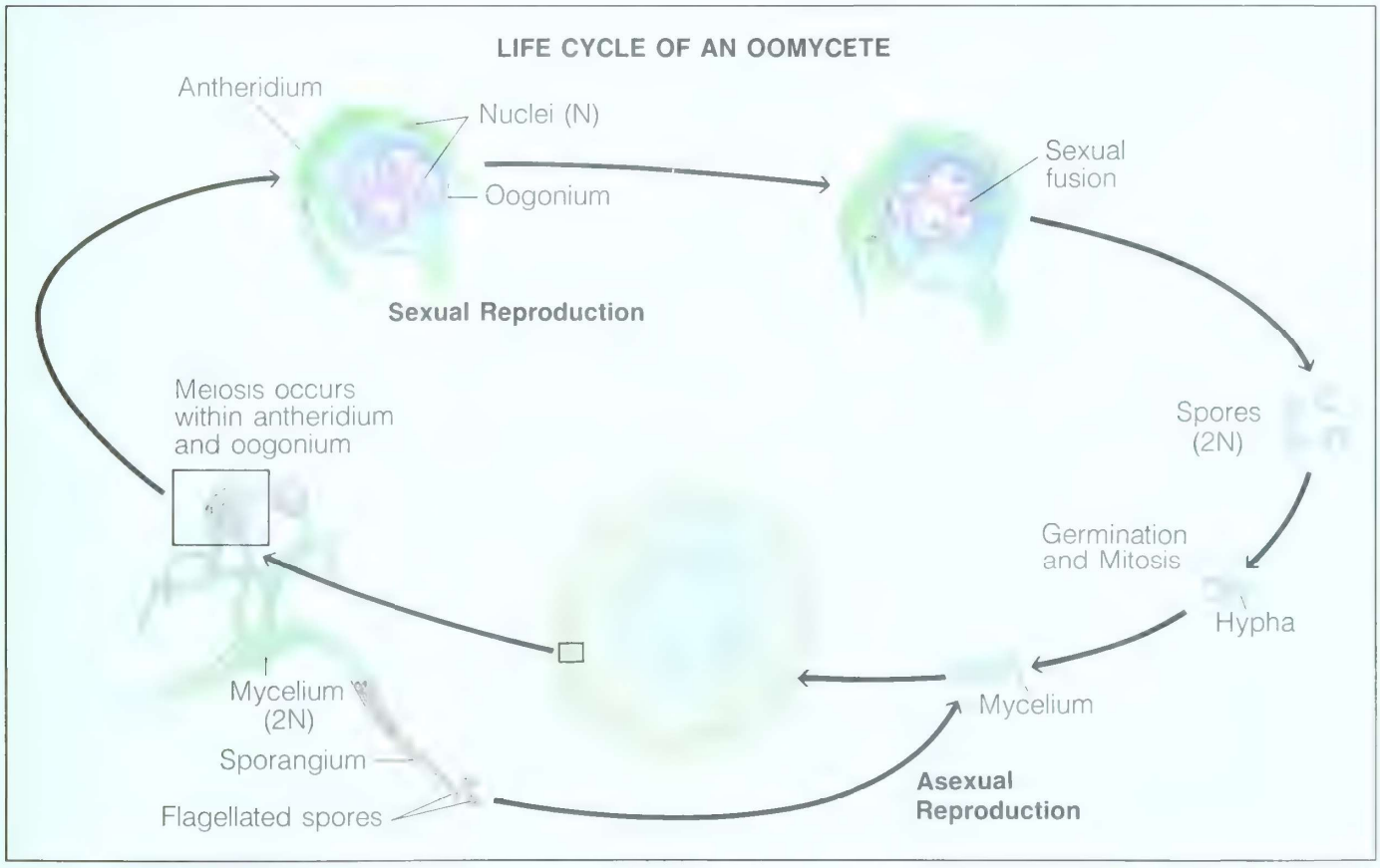




Figure 19–5 *The black bread mold* Rhizopus stolonifer, *a zygomycete, is commonly found growing on bread. The round black-colored structures at the top of the threadlike hyphae are the sporangia, or spore cases.*

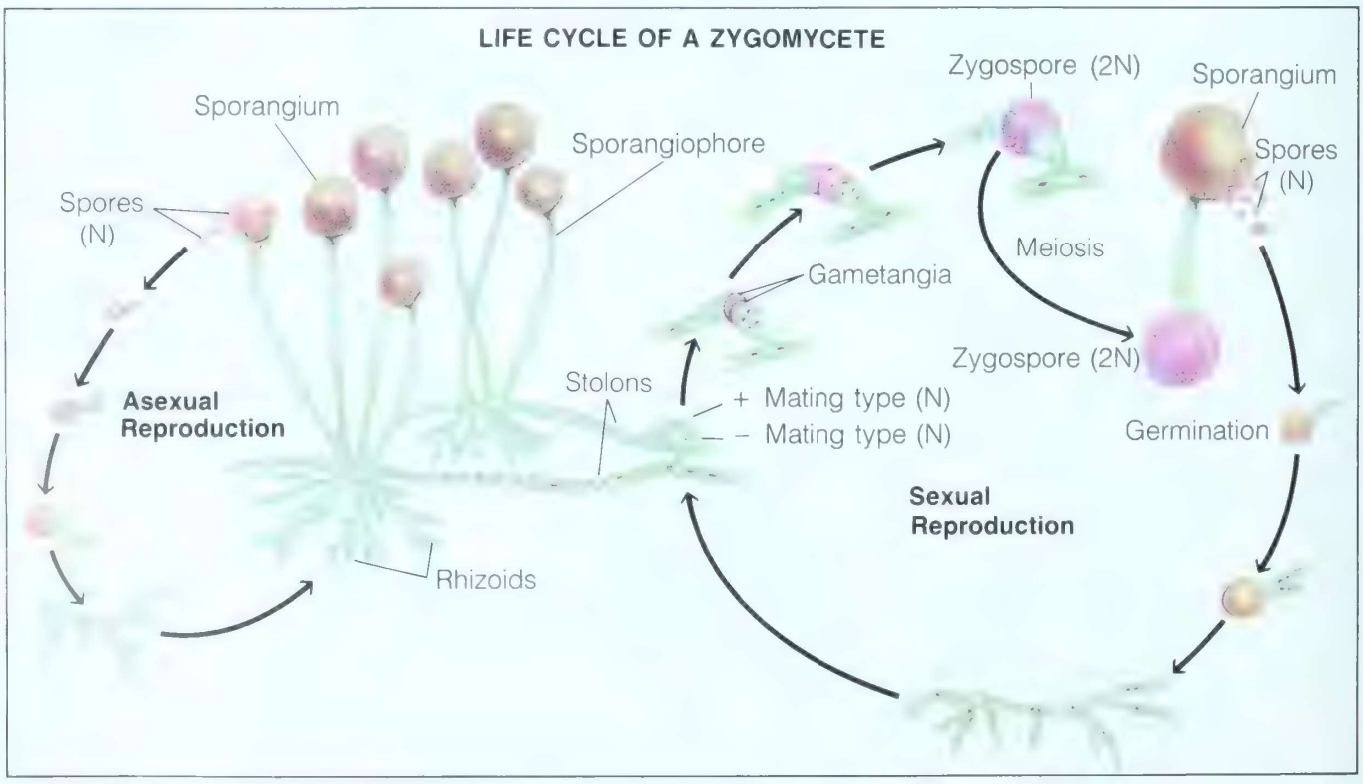
Sexual reproduction takes place in specialized structures that are formed by the hyphae. One of these structures, called the antheridium (an-thuh-RIHD-ee-uhm), produces sperm cells (male gametes). The other structure, called the oogonium, produces egg cells (female gametes). Fertilization occurs within the oogonium and, like spores, the zygotes that form develop into new organisms.

Zygomycota—Common Molds

Fungi that belong to the phylum Zygomycota (zigh-go-migh-KOHT-uh) are called zygomycetes and are terrestrial organisms. During sexual reproduction, they form a thick-walled zygote known as a **zygospore.** The hyphae of zygomycetes lack cross walls although there are cross walls present that isolate the reproductive structures from the rest of the hypha. We have all had some experiences—most often unpleasant ones—with members of this phylum. These common molds are the molds that grow on meat, cheese, and bread.

An example of a zygomycete is the black bread mold *Rhizopus stolonifer.* You can grow this mold yourself by exposing a slice of freshly baked bread (not the processed kind) to some airborne dust. Then keep the bread from drying out by putting it in a covered container and placing it in a warm spot.

Figure 19–6 *Sexual reproduction in black bread mold occurs when two hyphae from different mating types fuse, forming gametangia. The gametangia develop into a zygospore, which grows into new hyphae that form sporangia. Asexual reproduction occurs when the spores are discharged from the sporangia.*



If you were to examine the fuzz with a magnifying glass, you would see tangles of delicate hyphae, or mycelia. Actually, you would be seeing more than one kind of hypha. The rootlike hyphae that penetrate the surface of the slice of bread are called **rhizoids.** Rhizoids anchor the fungus to the bread (much like roots anchor a plant), release digestive enzymes, and absorb digested organic material. The stemlike hyphae that run along the surface of the bread are called **stolons.** And the hyphae that push up into the air are the sporangiophores, which form sporangia at their tips.

During asexual reproduction, sporangia produce spores. A single sporangium may contain as many as 40,000 spores. When fully developed, the sporangium opens, scattering the spores to the wind. Under proper conditions of warmth and moisture, the spores germinate, producing new masses of hyphae.

Sexual reproduction occurs in bread molds and other zygomycetes when two hyphae from different mating types come together, forming gametangia (gamete-producing structures). Haploid gametes are produced in the gametangia. Gametes of one mating type fuse with gametes of the opposite mating type, forming diploid (2N) nuclei. A thick wall develops around the nuclei, producing a zygospore. The tough, resistant zygospore may remain dormant for months. Eventually, when conditions become favorable, the zygospore germinates, undergoes meiosis, and develops into a hypha. The hypha then forms a sporangium and releases spores. Each spore can develop into a new mycelium.

In zygomycetes, as in other organisms, the main function of a sexual reproductive process is to produce new combinations of genetic information. The sexual reproductive process is an effective way to maintain genetic diversity in a species.

Ascomycota—Sac Fungi

The phylum Ascomycota (as-kuh-migh-KOHT-uh) is the largest phylum of the kingdom Fungi. There are more than 30,000 species of ascomycetes, as members of this phylum are called. The nuclei in the hyphae of ascomycetes are separated by cross walls so that individual cells do exist within the organism. In the cross walls, however, there are tiny openings through which the cytoplasm and the nuclei can move. Some ascomycetes, such as the morels, are large enough to be visible when they grow above the ground. Others, such as yeasts, are microscopic.

The life cycle of an ascomycete usually includes both asexual and sexual reproduction. Asexual spores are formed at the tip of specialized hyphae called **conidiophores** (koh-NIHD-ee-uh-forz). Because these spores are very fine, they are called **conidia** (koh-NIHD-ee-uh; singular: conidium) from the Greek word *konis*, which means dust.

Figure 19–7 *Ascomycetes are the largest phylum of fungi, containing 30,000 species. Among the ascomycetes are the common morel (bottom) and a type of cup fungus (top).*



Sexual reproduction in ascomycetes involves the formation of an **ascus,** or tiny sac. The ascomycetes are named for this reproductive structure. In most ascomycetes, sexual reproduction occurs between two different mating types (+ and −), which produce gametangia. The gametangia grow together to allow the haploid (N) nuclei to fuse. The cell that results from this fusion begins to develop into a structure that forms the ascus. See Figure 19–8. At first the cell has two nuclei, indicating that the nuclei of the two mating types do not fuse right away. When fusion does eventually occur, a diploid (2N) zygote is formed. The fusion is quickly followed by meiosis, producing 4 haploid cells. In most ascomycetes, meiosis is followed by a round (or two) of mitosis, so that 8 or 16 cells are found within the ascus. The cells produced within the ascus are known as **ascospores.** Like conidia, ascospores are capable of growing into new organisms.

The fruiting bodies of ascomycetes can be spectacular. A fruiting body is the part of the fungus that you see above the ground. It contains the spore-producing structures. The morel is an edible ascomycete in which the fruiting body bearing the asci has become the largest visible part of the organism.

The yeasts, which are unicellular, are one of the most interesting groups of ascomycetes. Most of their reproduction is asexual and takes place by mitosis and by budding. Budding is the formation of a smaller cell from a larger one.

Under the right circumstances, yeasts also reproduce sexually. They form asci that contain ascospores. Most scientists

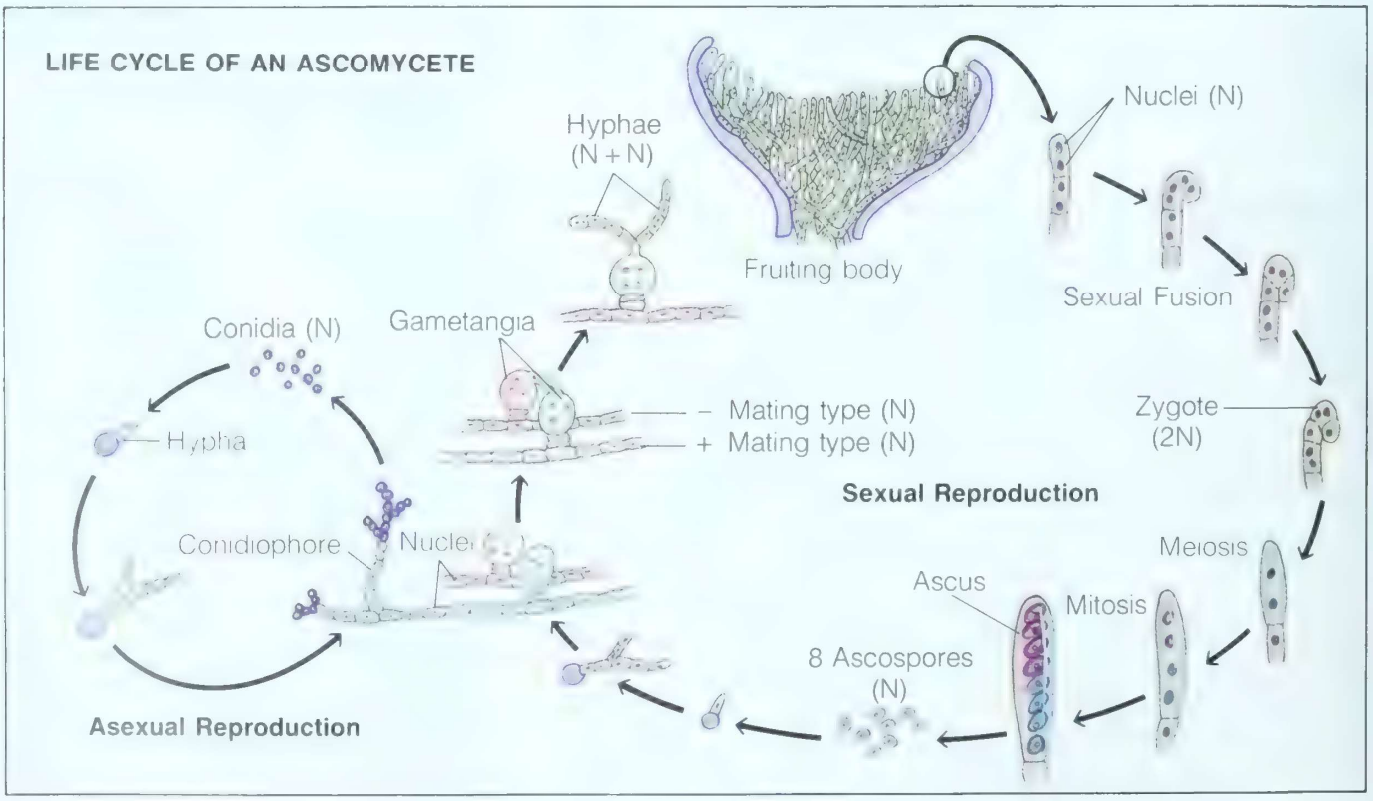


Figure 19–8 *As in most fungi, the life cycle of ascomycetes includes both asexual and sexual reproduction. During asexual reproduction, spores called conidia are formed at the tip of conidiophores, or special hyphae. During sexual reproduction, an ascus, or tiny sac that contains ascospores, forms.*

believe that yeast evolved from more complicated (and more typical) ascomycetes that lost the ability to form hyphae and became unicellular.

You probably think of yeast as the dry granules used to make bread, cakes, and rolls. The dry granules actually contain ascospores, which become active in a moist environment. By adding a small amount of the yeast granules to a mixture of water and sugar and waiting less than an hour, you would be able to observe under a microscope mitosis in the rapidly growing yeast cells.

Basidiomycota—Club Fungi

Most of the organisms that we call mushrooms belong to the phylum Basidiomycota (buh-sihd-ee-uh-migh-KOHT-uh) and are known as basidiomycetes. The phylum gets its name from a specialized reproductive structure that resembles a club. This spore-producing structure is called a **basidium** (buh-SIHD-ee-uhm; plural: basidia). In mushrooms, basidia are found in the cap.

Basidiomycetes undergo what is probably the most elaborate life cycle of all the fungi. A **basidiospore** germinates to produce haploid primary mycelia. The haploid primary mycelia of different mating types fuse. A secondary mycelia containing two nuclei—one nucleus from each mating type—is formed. (The nuclei themselves do not fuse at this stage.)





Figure 19–9 *All basidiomycetes, or club fungi, are composed of masses of hyphae. The coral fungus (top, left), shaggy mane fungus (right), and jelly fungus (bottom, left) illustrate the many different shapes that masses of hyphae can form.*



Figure 19–10 *This photograph shows the underside of a parasol mushroom. Notice the gills and the stalk. The ringlike structure on the stalk is called the annulus.*

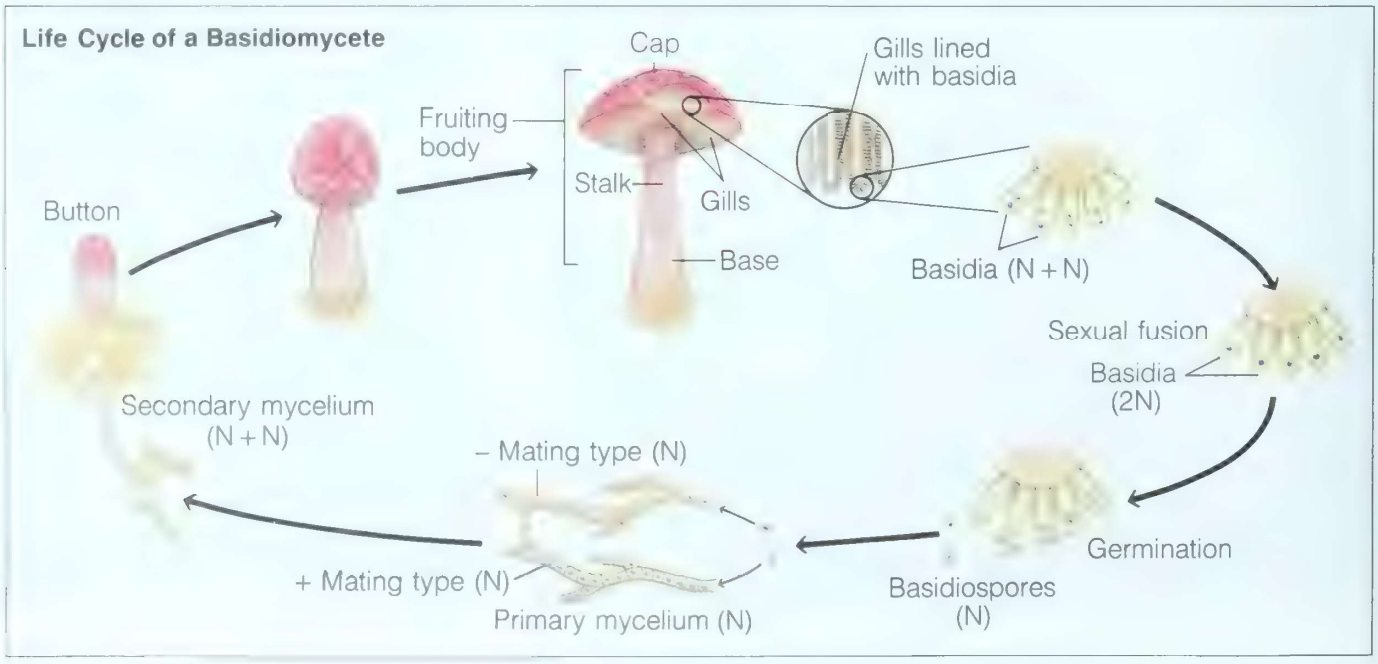
The secondary mycelia may grow in the soil for many years, reaching an enormous size. When the right combination of moisture and nutrients is achieved, the formation of a fruiting body (spore-producing structure) begins. The "mushroom" that you see above the ground is actually a fruiting body, which consists of a base, a stemlike stalk, and an umbrella-shaped cap. The mycelia are found below the ground.

The mushroom (fruiting body) begins as a mass of growing hyphae that forms a button, or thick bulge, at the soil's surface. The bulge expands with astounding speed and force, producing fully developed mushrooms overnight. This rapid growth occurs because the cytoplasm from thousands of hyphae in the soil quickly streams into the growing mushroom, enlarging it and producing a great amount of force.

When the mushroom cap opens, it exposes hundreds of tiny gills on its underside. Each gill is lined with basidia. Within a few days, the two nuclei in each basidium fuse to form a true diploid (2N) zygote cell. The diploid cells quickly undergo meiosis, forming clusters of haploid basidiospores. The basidiospores form at the edge of each basidium and, within a few hours, are ready to be scattered. Mushrooms are truly amazing reproductive structures—a single mushroom can produce as many as one billion spores!

In addition to common mushrooms, this phylum includes shelf (bracket) fungi, which grow near the surfaces of dead or decaying trees. The visible bracketlike structure that forms is actually a reproductive structure, and it too is an amazing producer of spores. Puffballs, toadstools, jelly fungi, and plant parasites known as rusts are other examples of basidiomycetes.

Figure 19–11 *The most familiar basidiomycetes are the mushrooms. The mushroom cap, which contains basidia, is made up of masses of tightly packed hyphae. Basidia are the club-shaped structures that produce the basidiospores.*



Deuteromycota—Imperfect Fungi

The phylum Deuteromycota (doo-ter-uh-migh-KOHT-uh) includes fungi that cannot be placed in any of the other phyla because their sexual reproduction has never been observed. The word imperfect is a botanical term referring to a lack of sexual reproduction; hence, the name imperfect fungi.

A great majority of the deuteromycetes (as they are also known) closely resemble ascomycetes. Others are similar to basidiomycetes. And a few are much like zygomycetes. An example of a deuteromycete that is similar to ascomycetes is *Penicillium*. *Penicillium* is a mold that frequently grows on fruit and is the source of the antibiotic penicillin. *Penicillium* forms large mycelia on the surfaces of its food source. And like ascomycetes, *Penicillium* reproduces asexually by means of conidia. Biologists believe that *Penicillium* may have developed from a type of ascomycete that lost the ability to carry out the sexual phase of its life cycle.

The deuteromycetes include some of the most infamous members of the kingdom Fungi: those that are responsible for ringworm, athlete's foot, and other skin infections that affect humans. Other deuteromycetes cause several plant diseases, including black spot of roses and early tomato blight.



Figure 19–12 Aspergillus niger, *a deuteromycete, contains spore-bearing structures called conidiophores (inset), which form at the tips of hyphae.*

Figure 19–13 *Five phyla of fungi*

Phylum	Examples	Characteristics	Reproduction	
			Asexual	Sexual
Oomycota (protistlike fungi)	Water molds, downy mildew, potato blight fungus	Cell walls with cellulose; coenocytic diploid hyphae	Flagellated oospores in sporangia	Fusion of gametes in gametangia resulting in oospores
Zygomycota (common molds)	*Rhizopus* (black bread mold), *Pilobolus* (a dung fungus)	Cell walls with chitin; coenocytic hyphae	Unflagellated spores in sporangiophores	Fusion of gametes in gametangia resulting in zygospores
Ascomycota (sac fungi)	Yeasts, morels, truffles, *Neurospora* (red bread mold)	Hyphae divided by perforated cross walls; short stage in which cells have two nuclei	Conidia on conidiophores	Fusion of hyphae resulting in ascospores in ascus
Basidiomycota (club fungi)	Mushrooms, puffballs, bracket fungi, rusts, jelly fungi, toadstools	Hyphae divided by perforated cross walls; long stage in which cells have two nuclei	None or conidia on conidiophores	Fusion of cells on tips of hyphae resulting in basidiospores on a basidium
Deuteromycota (imperfect fungi)	*Penicillium*, *Aspergillus*, ringworm and athlete's foot fungus, black spot on roses fungus, tomato blight fungus, cucumber scab fungus	Some resemble ascomycetes; others similar to basidiomycetes; few like zygomycetes	Conidia on conidiophores	None known

SCIENCE, TECHNOLOGY, AND SOCIETY **BREAKTHROUGH**

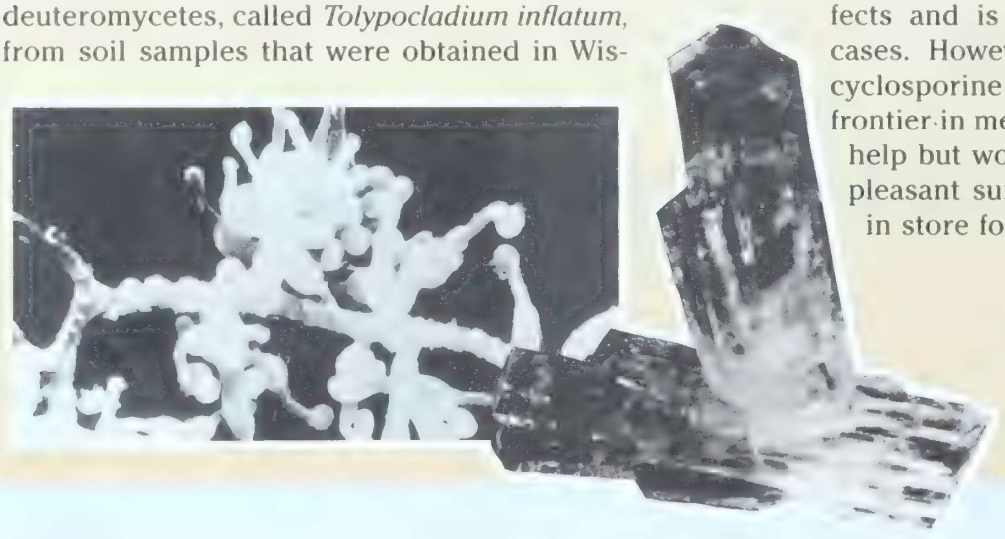
Cyclosporine

When disease or injury destroys one of a patient's vital organs, physicians often try to transplant the organ from a donor into the patient. This procedure, however, poses a serious and often life-threatening problem. In most transplants, the recipient's immune system recognizes the transplanted organ tissue as foreign and attacks it, causing the rejection of the organ. It was not until 1972 that a substance was discovered that would suppress the immune system's response to a foreign organ.

While working in Switzerland, Jean Borel, a Swiss immunologist, isolated a new strain of deuteromycetes, called *Tolypocladium inflatum*, from soil samples that were obtained in Wisconsin and Norway. This strain produced a substance, later named cyclosporine, that was capable of suppressing the immune system's response to transplanted organs. In other words, the substance was remarkably effective in preventing transplant rejection.

Cyclosporine has revolutionized the field of medical transplantation. Before it became available in 1979, fewer than half of all kidney transplants were successful. With the advent of cyclosporine, the percentage of survival has risen to 90 percent.

Cyclosporine is indeed a wonder drug—but it is not perfect. It causes severe side effects and is not successful in all cases. However, the discovery of cyclosporine has opened up a new frontier in medicine, and we cannot help but wonder how many other pleasant surprises the fungi have in store for us in the future.



Synthetic crystals of cyclosporine (right) and fungus Tolypocladium inflatum *that produces cyclosporine (left)*

19–1 SECTION REVIEW

1. Describe the structure of a typical fungus.
2. How do fungi obtain food?
3. What are the five phyla of fungi? Describe the characteristics of each.
4. What are some methods by which fungi reproduce?
5. Sensitive tests show that tissue from several mushrooms gathered near the base of a tree are genetically identical. How might you explain this finding?

19–2 Fungi in Nature

Section Objectives

- Describe some methods of spore dispersal.
- Discuss the symbiotic relationships of fungi.
- Summarize the beneficial and harmful effects of fungi.

As you have learned, fungi live by feeding on living organisms or on the remains of dead ones. Although this may paint a grim picture of fungi—linking them with death and decay—they are actually some of the most beautiful organisms on Earth. In this section we will take a very human-centered view of the kingdom Fungi as we examine what effects these organisms have on us and the rest of the living world.

Ecological Significance

The principal role fungi play in the environment is to decompose and recycle living material. Imagine a world in which fungi do not exist: The ground would be littered with leaves, fallen wood, and the bodies of dead animals. What impact would this have on organisms living in this world?

First, you may recall that the material of which a living organism is composed is rich in chemical energy. Because this energy exists, we can make a crackling fire out of wood or a good snack out of an apple. If such material does not undergo decay, the energy it contains will be lost. Second, many organisms, particularly green plants, require small amounts of trace elements and nutrients in order to survive. During their development, green plants remove these materials from the soil. If the materials are not eventually returned, the soil will soon be depleted and the destruction of plants, as well as animals whose lives depend on the plants, will result.

Figure 19–14 *Together with bacteria, fungi—such as this mushroom—are the major decomposers and recyclers of living material on Earth.*



WHERE ARE FUNGI FOUND? There are remarkably few places on Earth where one species of fungus or another does not make its home. Even more amazing is the fact that fungal spores are found in almost every environment. Indeed, this is why molds seem to spring up in any location that has the right combination of moisture and food.

In many places, large mycelia occupy a nearly permanent place in the environment and last for many years. A mushroom develops from a mycelium located just below the ground. As the mycelium grows, new mushrooms pop up from the mycelium wherever nutrients are available. This is why strands of mushrooms are often part of the same organism.

As time goes by, the available nutrients near the center of the mycelium become depleted, causing new mushrooms to sprout only at the edges of the mycelium. This produces a ring of mushrooms called a fairy ring. People once thought fairies dancing in circles during warm nights produced these rings, so they called them fairy rings. Over many years, fairy rings can become enormous, forming rings 10 to 20 meters in diameter.

SPORE DISPERSAL Many fungi, including most common mushrooms, produce dry, almost weightless, spores that are



Figure 19–15 *The giant puffball contains as many as 7 trillion spores. In the common puffball, the dispersal of spores can be triggered by the slightest touch, even by a raindrop.*

easily scattered by the wind. On a clear day, a few liters of fresh air may contain hundreds of spores from many species of fungi. Some of these species have remarkable ways of getting their spores into places where they are likely to grow.

For fungi, spore placement is crucial. A single spore has a slim chance of finding the proper combination of temperature, moisture, and food so that it can germinate. Even under the best of circumstances, the odds of a spore producing a mature organism can be more than one in a billion. So you can see why anything that might help reduce those odds is considered a selective advantage to that species.

The puffballs (basidiomycetes) go to extremes to produce their spores. A mature puffball is virtually a warehouse of spores. The simple action of a raindrop falling on a puffball can release thousands of spores in a small cloud of dust.

Other species of fungi trick animals into dispersing their spores for them. The stinkhorns (*Phallus*) go so far as to mimic rotting meat. The surface of a stinkhorn is covered with a fluid that has the odor of rotting flesh. Flies are drawn to the stinkhorn. Then they land on the stinkhorn to taste the sticky fluid. Once ingested, the spore-containing fluid will pass unharmed out of the flies' digestive systems, depositing spores over great distances.

Symbiotic Relationships

Many fungi associate with members of other species in symbiotic relationships. In some of these relationships, such as early tomato blight, fungi are harmful. But in other cases, fungi form relationships in which both partners benefit. Such is the situation with the **lichens** (LIGH-kuhnz) and **mycorrhizae** (migh-koh-RIGH-zee).

Lichens are symbiotic partnerships between a fungus and a photosynthetic organism. The fungus in the relationship is usually an ascomycete, although it can be a basidiomycete. The photosynthetic organism is either a cyanobacterium (blue-green bacterium) or a green alga.

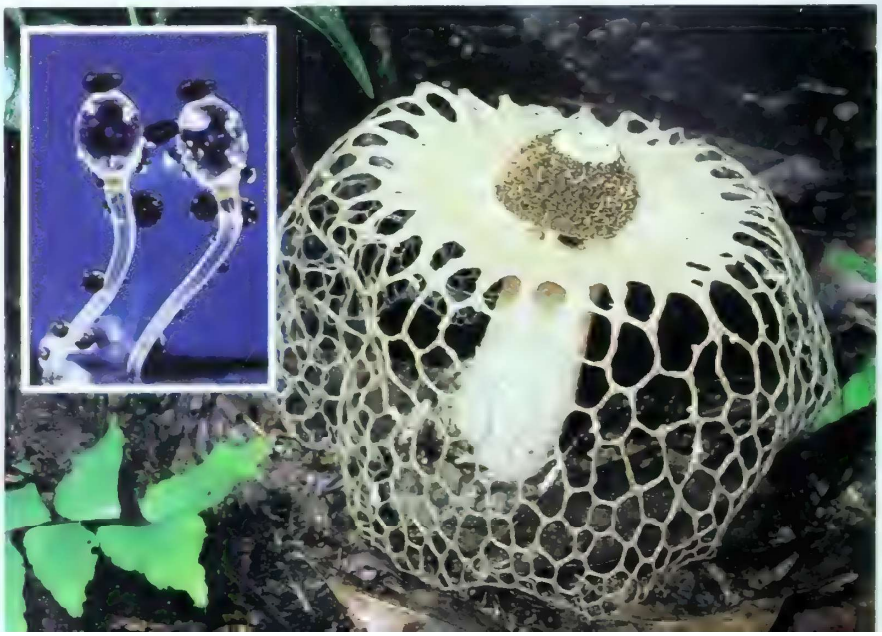


Figure 19–16 *Fungi have remarkable ways of dispersing their spores. The lacy stinkhorn attracts flies by producing a spore-containing fluid that has the odor of rotting flesh. The spores pass unharmed through the flies' digestive system and are deposited over great distances.* Pilobolus *(inset) fires its sporangia at an initial speed of 50 kilometers per hour—as far as 1 meter.*

Because they are extremely resistant to drought and cold, lichens grow in places where few other organisms can survive—on dry, bare rock in deserts and on the tops of mountains. Lichens are able to survive in these harsh environments because of the relationship between the two partner organisms. The alga carries out photosynthesis, providing the fungus with a source of organic nutrients. The fungus, in turn, provides the alga with water and minerals that it has collected from the surfaces on which it grows.

Lichens are often the first organisms to enter barren environments, gradually breaking down the rocks upon which they grow. In this way, lichens help in the early stages of soil formation and eventually form an environment that is hospitable to other organisms.

Another symbiotic relationship, called mycorrhizae, forms between fungi and green plants (mycorrhiza means fungus root in Greek). The tiny hyphae of the fungi aid plants in absorbing water, minerals, and nutrients. They do this by producing a network that covers the roots of the plants and increases the effective surface area of the root system. The plants, in turn, provide the fungi with the products of photosynthesis.

An example of mycorrhizae involves orchids, which are considered by many as the most beautiful of the flowering plants. The seeds of orchids germinate in nature only in the presence of a certain species of fungi. These fungi penetrate the seed, providing it with moisture and food during the early stages of the orchid's growth.

The symbiotic relationships between green plants and fungi have existed for millions of years. Some of the earliest fossils of land plants contain evidence of fungi. This suggests that fungi may have played a crucial role in the colonization of the land by green plants.



Figure 19–17 *Lichens generally grow in three forms. Crustose lichens are flat (top), foliose lichens resemble leaves (center), and fruticose lichens grow upright (bottom).*

Fungi and Human Life

Two of the oldest discoveries of civilization are the techniques for making bread and alcohol. Interestingly enough, both techniques rely on a cooperative effort between humans and fungi and provide an important example of the many ways in which humans have made use of this living kingdom.

Because of the role yeasts play in baking and brewing, one might argue that they are the most important fungi to humans. The common yeasts used for baking and brewing are members of the genus *Saccharomyces* (sak-uh-roh-MIGH-seez). To grow these yeasts, a rich nutrient mixture containing very little oxygen is prepared. In brewing, it is a vat of grape juice or barley malt. In baking, it is a mound of thick dough. The yeasts within the mixture quickly begin the process of alcoholic fermentation in order to obtain enough energy to survive. The byproducts of alcoholic fermentation are carbon dioxide and alcohol. The carbon dioxide gas makes bread rise (by producing bubbles



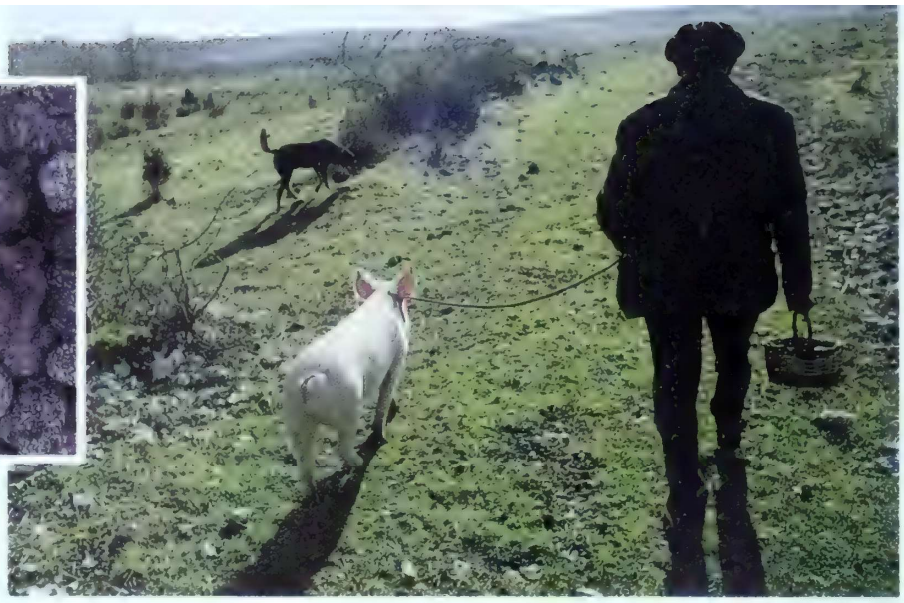


Figure 19–18 *In France, pigs are used in the search for truffles. Truffles (left) are considered by many people to be a rare and delicious treat.*

within the dough) and beverages bubble. The alcohol is used in alcoholic beverages or as a fuel.

As you may recall from Chapter 12, yeasts are now used for genetic engineering. Because they are eukaryotes, yeasts often process the protein products of genes cloned from other eukaryotes more efficiently than bacteria (prokaryotes) do. It is not impossible to imagine that sometime in the near future, genetically engineered yeasts may be used to produce a wide variety of biologically important compounds.

Some types of fungi have long been considered a delicacy by humans. One example are the mushrooms (basidiomycetes). There are approximately 10,000 different species of mushrooms found throughout the world. Many of these mushrooms are cultivated and prepared by people and then sold in supermarkets and specialty food shops. These species of mushrooms are easy to grow, taste good when properly cooked, and do not pose a danger to anyone who eats them.

Figure 19–19 *Although the death cap mushroom looks harmless, eating only one cap of it can prove fatal.*



Wild mushrooms are a different story: Although some are edible, many are poisonous. You may have heard someone say that only toadstools are poisonous, whereas mushrooms are safe to eat. Unfortunately, this is not true. For toadstools are mushrooms. Furthermore, poisonous mushrooms do not belong to just one order or family of basidiomycetes.

Because many species of poisonous mushrooms look almost identical to edible mushrooms, it is best not to pick or eat any mushrooms found in the wild. Instead, mushroom gathering should be left to experts who can positively identify each mushroom they collect. The result of eating a poisonous mushroom is severe illness and sometimes death.

History records that the Roman Emperor Claudius was given a plate of mushrooms, known as deathcaps (*Amanita phalloides*), by his palace guards in a plot to remove him from the throne. He ate heartily. Although the deathcaps were delicious, the meal served its purpose and the throne was empty the next day.

Diseases Caused by Fungi

Not all fungi are suited to human needs. Some species of fungi cause tremendous losses of food and crops every year, and some cause disease in humans.

POTATO BLIGHT In their own way, the plant diseases caused by fungi have influenced history. In 1845, the potato crops of Ireland and Europe were devastated by a fungus that destroyed the foliage of the plant and infected the potatoes themselves. The culprit was the oomycete *Phytophthora infestans,* which causes the disease known as late potato blight.

Potatoes that are infected with the blight may appear normal at harvest time. But within a few weeks, the fungus makes its way into the potato, reducing it to a spongy sac of spores and dust. During the years that followed the potato blight infection, more than one million people in Ireland died of starvation as the result of the destruction of their main food source. Many others left Ireland and emigrated to the United States rather than face a similar fate.

WHEAT RUST Another fungal disease, called rust, affects wheat, one of the most important crops grown in North America. During the early part of this century, farmers in the Midwest watched helplessly as their plants developed tiny rustlike spots on their leaves. These spots gradually expanded and killed the plants before they could be used to produce grain. A similar incident occurred in the 1930s, when great plagues of rust disease added to the economic misery of the Great Depression. During this time, farmers not only lost their crops but their farms as well.



Figure 19–20 *This electron micrograph shows a cluster of spores of the wheat rust fungus bursting through the plant's epidermis, or outer covering.*

Rusts are caused by a type of basidiomycete that needs two different plants in order to complete its life cycle. Spores produced by the rust in the barberry plant are carried by the wind into wheat fields. There the spores germinate and infect wheat plants. The patches of rust produce a second type of spore that infects other plants, allowing the disease to spread through a field of wheat at an alarming rate.

Later in the year, often after the wheat crop has been ruined, new kinds of spores are produced by the rust. These black-colored spores are tough enough to survive through the winter. In the spring, they go through a sexual phase and produce spores that infect the barberry plant. Once on the barberry leaves, the rust produces the spores that infect the wheat plant, and the cycle continues. Fortunately, the life cycle of the rust can be broken and the disease brought under control by destroying the barberry plant.

OTHER PLANT DISEASES Fungi that attack crop plants cause other diseases such as corn smut, which destroys the corn kernels, and mildews, which infect a wide variety of fruits. It is estimated that fungal diseases are responsible for the loss of approximately 15 percent of the crops grown in temperate regions of the world. In tropical areas, where high humidity favors fungal growth, the loss of crops is sometimes as high as 50 percent. As you can see, these organisms are in direct competition with us for our own food supply.

HUMAN DISEASES Although most fungal diseases are associated with plants rather than animals, there are several fungi that cause disease in humans. These pathogenic (disease-causing) organisms are deuteromycetes (imperfect fungi). One type can infect the areas between the toes, causing athlete's foot. The fungus forms a mycelium directly within the outer layers of skin. This produces a red, inflamed sore from which the spores can easily spread from person to person.

When the same fungus infects the skin of the scalp, it produces a red scaling sore known as ringworm. Contrary to popular belief, ringworm is not caused by a worm; it is caused by a fungus. Ringworm can be passed from person to person by the exchange of hats, combs, and athletic headgear. The fungi that cause athlete's foot and ringworm can be destroyed by the application of fungicides, or chemicals that kill fungi.

Another type of fungal disease that infects humans is caused by the yeast *Candida albicans*. This fungus grows in moist regions of the body, such as the mouth and the urinary tract. Usually its growth is kept in check by competition from bacteria and by the body's immune system. This normal balance can be upset by many factors, including the use of antibiotics, which kill bacteria, or by damage to the immune system. When this happens, *Candida* may produce thrush, a serious and painful mouth infection, or infections of the urinary tract.



Figure 19–21 *This ant has been killed by a fungus called* Cordyceps lloydii. *Once the fungus's tiny spore enters the insect's body, it begins to multiply. Within days, the fungus digests all but the ant's outer covering. The umbrellalike structures growing out of the ant's body are the fungus's fruiting bodies.*

ANIMAL DISEASES As serious as human fungal diseases can be, few approach the deadliness of *Cordyceps lloydii.* This fungus infects ants in forests near the basin of the Amazon River in Venezuela. Microscopic spores become lodged in the ant, where they germinate and produce enzymes that slowly penetrate the insect's tough exoskeleton (external skeleton). Once the spores have gained entry, they multiply in the insect's blood, digesting all its cells and tissues until the insect dies. To complete the process of digestion, hyphae develop, cloaking the decaying exoskeleton in a web of fungal material. Reproductive structures, which will produce more spores that will spread the infection, then emerge from the ant's remains.

19-2 SECTION REVIEW

1. What is the major role of fungi in the environment?
2. What are some methods by which fungi disperse their spores?
3. Describe the role of fungi in two important symbiotic relationships.
4. Why can lichens survive in harsh environments?
5. What are some beneficial effects of fungi? Some harmful effects?
6. Why are fungi a more serious problem in tropical regions of the world than they are in temperate regions?

LABORATORY INVESTIGATION

COMPARING A MOLD AND A MUSHROOM

PROBLEM

What are some similarities and some differences between a mold and a mushroom?

MATERIALS *(per group)*

- bread
- petri dish
- 2 medicine droppers
- 2 glass slides
- dissecting needle
- 2 coverslips
- microscope
- iodine solution
- paper towel
- mushroom
- forceps

PROCEDURE

1. Moisten a piece of bread with tap water. Place the moistened bread in the bottom of the petri dish.
2. Allow the petri dish to remain uncovered for 30 minutes. After 30 minutes, put the cover on the petri dish.
3. Place the petri dish in a warm, dark place where it will remain undisturbed for 1 to 2 weeks. Examine the bread daily for mold.
4. After the bread becomes moldy, use a medicine dropper to place a drop of water in the center of a glass slide.
5. With the dissecting needle, separate a small piece of the mold from the bread. **CAUTION:** *Be careful when using a dissecting needle.* Add the mold to the water on the glass slide and cover with a coverslip.
6. Locate some hyphae (threadlike filaments) with the low-power objective of the microscope. Then switch to the high-power objective and use the fine adjustment to locate some hyphae. Notice their color.
7. With the other medicine dropper, place a drop of iodine solution at one edge of the coverslip. Hold a piece of paper towel at the opposite edge of the coverslip to draw the iodine solution across the coverslip.
8. Examine the hyphae again under the low and high powers of the microscope. Observe the shape and arrangement of the hyphae. Notice the sporangia, or bulb-shaped structures, at the ends of some of the hyphae. Make a labeled diagram of the structures of the mold.
9. Place a drop of water in the center of the second glass slide.
10. Break the stalk off the mushroom slightly below the place where the stalk meets the cap. Insert the dissecting needle just under the surface of the stalk and carefully remove a small flap of the stalk.
11. With the forceps, peel off a thin layer of mushroom that runs parallel to the stalk. This layer contains the secondary mycelia (mass of hyphae).
12. Place the thin layer of mycelia in the water on the glass slide. Flatten the layer before covering it with a coverslip.
13. Repeat steps 6 through 8 using the mass of hyphae of the mushroom.

OBSERVATIONS

1. How many different kinds of mold do you see growing on the bread?
2. What is the color of the hyphae in the bread mold? In the mushroom stalk?
3. Describe the shape and arrangement of the structures of the mold and the mushroom.

ANALYSIS AND CONCLUSIONS

1. Explain why the bread was exposed to the air.
2. Why was the bread allowed to remain undisturbed in a warm, dark place for several weeks?
3. What was the purpose of examining the unstained mold and mushroom structures under the microscope?
4. How are a mold and a mushroom similar? How are they different?

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

19–1 The Fungi

- Fungi are eukaryotic heterotrophs that are placed in the kingdom Fungi. They may be saprophytes, parasites, or symbionts.
- Together with bacteria, fungi are the major decomposers, or organisms of decay.
- Hyphae secrete digestive enzymes that break down food into simpler molecules and absorb them into their cells.
- The body of a fungus consists of tiny filaments tangled together into a thick mass called a mycelium. The individual filaments are called hyphae.
- Most fungi reproduce asexually and sexually.
- The kingdom Fungi is divided into five phyla: Oomycota, Zygomycota, Ascomycota, Basidiomycota, and Deuteromycota.
- Oomycetes reproduce asexually by producing flagellated spores in structures called sporangia, or spore cases. Sexual reproduction results in the formation of male and female gametes. The nuclei of these gametes fuse, forming a diploid cell.
- Zygomycetes, ascomycetes, basidiomycetes, and deuteromycetes reproduce asexually by spores, which develop in sporangia. With the exception of deuteromycetes, these fungi reproduce sexually when two mating types come into contact, producing cells in the gametangia. The sexual part of the life cycle of deuteromycetes has never been observed.
- Ascomycetes produce spores sexually in an ascus, or tiny sac. Basidiomycetes produce spores in club-shaped basidia.

19–2 Fungi in Nature

- The principal role that fungi have in the environment is to decompose and recycle living material.
- Lichens are symbiotic partnerships between a fungus and a photosynthetic organism. The fungus is usually an ascomycete, and the photosyntheic organism is either a cyanobacterium or a green alga.
- Some fungi cause tremendous losses of food and crops, and some cause disease in humans and other animals.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

19–1 The Fungi

fungus
decomposer
mycelium
hypha
sporangium
sporangiophore
gametangium
zygospore
rhizoid
stolon
conidiophore
conidium
ascus
ascospore
basidium
basidiospore

19–2 Fungi in Nature

lichen
mycorrhiza

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Fungi consist of tiny filaments called
   a. asci.
   b. hyphae.
   c. basidia.
   d. sporangia.
2. Fungi obtain nutrients by
   a. photosynthesis.
   b. external digestion of food.
   c. ingestion of small organisms.
   d. absorption through cilia.
3. What are the small rootlike hyphae in bread mold called?
   a. rhizoids
   b. mycelia
   c. basidia
   d. caps
4. Yeasts are
   a. ascomycetes.
   b. basidiomycetes.
   c. zygomycetes.
   d. deuteromycetes.
5. Basidiomycetes are also known as
   a. sac fungi.
   b. imperfect fungi.
   c. water molds.
   d. club fungi.
6. Lichens are symbiotic partnerships between a
   a. fungus and a plant.
   b. green alga and a cyanobacterium.
   c. fungus and a cyanobacterium.
   d. green alga and a plant.
7. Which fungal disease destroyed Ireland's main source of food in 1845?
   a. wheat rust
   b. potato blight
   c. corn smut
   d. cucumber scab
8. Athlete's foot is caused by a (an)
   a. oomycete.
   b. basidiomycete.
   c. deuteromycete.
   d. ascomycete.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Fungi are autotrophs.
2. Fungi reproduce by binary fission.
3. During asexual reproduction, zygomycetes form thick-walled zygotes called basidiospores.
4. In the bread mold, the hyphae that run along the surface of the bread are called stolons.
5. Mushrooms belong to the phylum Oomycota.
6. Sexual reproduction has never been observed in deuteromycetes.
7. A morel is a symbiotic partnership between a fungus and a photosynthetic organism.
8. Yeasts are used in the baking and brewing industries.

Word Relationships

A. *In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.*

1. oomycetes, ascomycetes, basidiomycetes, zygomycetes
2. zygomycetes, ascomycetes, basidiomycetes, deuteromycetes
3. athlete's foot, rust, thrush, ringworm
4. stolon, rhizoid, sporangiophore, zygospore
5. mushroom, morel, truffle, yeast

B. *An analogy is a relationship between two pairs of words or phrases generally written in the following manner: a:b::c:d. The symbol : is read "is to," and the symbol :: is read "as." For example, cat:animal::rose:plant is read "cat is to animal as rose is to plant."*

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

6. ascus:sac fungus::basidium:_____

7. water mold:oomycete::club fungus:_____

8. fungus and green alga:lichen::fungus and green plant:_____

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Discuss the general characteristics of fungi.

2. How do oomycetes differ from the other members of the kingdom Fungi? How do deuteromycetes differ?

3. Discuss reproduction in the bread mold *Rhizopus stolonifer.*

4. Explain the basis for the classification of fungi.

5. Why are yeasts useful in genetic research?

6. What is the ecological importance of lichens and mycorrhizae?

7. Why is the absence of oxygen important for fermentation by yeast?

8. Describe the life cycle of wheat rust.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. Identifying relationships Heavily polluted fresh water contains few fungi. How might this affect life in a lake?

2. Applying concepts Explain why there are more fungi in a forest than in a field.

3. Making predictions What would be the effect on humans of a fungicide capable of killing all types of fungi?

4. Classifying fungi Develop your own system of classification for the fungi. Draw a diagram to represent your system.

5. Relating concepts While on a walk in the forest, you come upon some fungi, similar to those shown in the photograph, growing from the trunk of a fallen tree. You examine the underside of one of the fungi with a magnifying glass and notice some club-shaped structures. To which phylum do these fungi belong? Explain your answer.



6. Using the writing process A debate is raging in your classroom. Some people argue that because fungi cause human disease and damage crops, they should be eradicated from Earth. Their case seems compelling. But you are responsible for defending the opposing viewpoint. Let the fungi be, you maintain. Write the script for the argument you would present in the debate.