

Fungus

I INTRODUCTION



Lichens of the Splash Zone of the Intertidal Region

Lichens are actually a combination of two entirely different types of living organisms, an alga and a fungus. This association is called a symbiotic relationship. In this particular type of symbiotic relationship neither partner can live independent of the other. Lichens are very slow growing and can survive very harsh environmental conditions and are ecologically significant in that they contribute to the weathering of solid rock.

G.I. Bernard/Oxford Scientific Films

Fungus, any member of a diverse group of organisms that—unlike plants and animals—obtain food by absorbing nutrients from an external source. The fossil record suggests that fungi were present 550 million years ago and may have evolved even earlier. Today thousands of different types of fungi grow on and absorb food from substances such as soil, wood, decaying organic matter, or living plants and other organisms. They range from tiny, single-celled organisms invisible to the naked eye to some of the largest living multicellular organisms. In Michigan for example, the underground portion of an individual *Armillaria* mushroom, a type of fungus, extends more than 12 hectares (30 acres). Other fungi are among the longest-lived organisms on Earth—some lichens, a living partnership of a fungus and an alga, are thought to be more than 4,500 years old.

A large and widely distributed group of organisms, fungi perform activities essential to the functioning of all natural ecosystems. They are among the foremost decomposers of organic matter, breaking down plant and animal remains and wastes into their chemical components. As such, fungi play a critical role in the recycling of minerals and carbon. Fungi's value to humankind is inestimable. Certain types of fungi, including several types of mold, have proven extremely valuable in the synthesis of antibiotics and hormones used in medicine and of enzymes used in certain manufacturing processes. Some fungi, such as mushrooms and truffles, are considered tasty delicacies that enhance a wide

variety of recipes. Not all fungi are beneficial—some damage agricultural crops, cause disease in animals and humans, and form poisonous toxins in food.

Common fungi include mushrooms, puffballs, truffles, yeasts, and most mildews, as well as various plant and animal *pathogens* (disease agents), such as plant rusts and smuts. Some experts estimate that there are 1.5 million fungus species, of which approximately 100,000 have been identified. The unique characteristics of fungi led scientists to classify these important organisms into a separate kingdom, Kingdom Fungi (also known as Mycetozoa). Certain fungus-like organisms, such as downy mildews, water molds (also known as oomycetes), and slime molds, once classified as fungi, are now placed in the Kingdom Protista.

II UNIQUE FEEDING METHOD

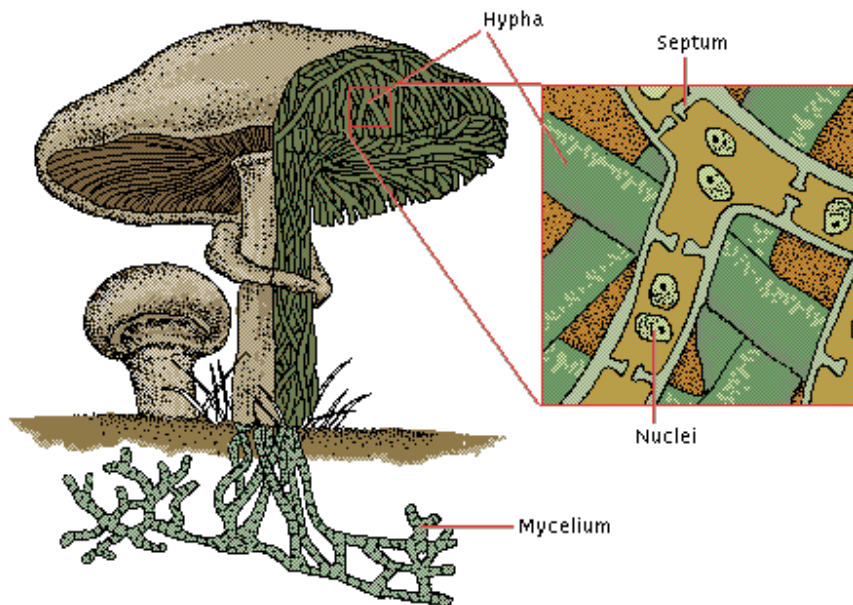
Fungi lack chlorophyll, the green pigment that enables plants to make their own food. Consequently, fungi cannot synthesize their own food the way plants do. In order to feed, fungi release digestive enzymes that break down food outside their bodies. The fungus then absorbs the dissolved food through its cell walls.

Depending as they do on outside sources for food, fungi have developed various living arrangements that enhance their opportunities for food absorption. Some fungi live as parasites, feeding on living plants, animals, and even other fungi. Certain fungus parasites injure plants and animals, causing millions of dollars of damage to farm animals, crops, and trees each year. For example, the fungus *Ophiostoma ulmi*, which causes Dutch elm disease, has killed tens of millions of elm trees around the world.

Fungi that obtain their food by breaking down dead organisms or substances that contain organic compounds, such as starch and cellulose, are called saprobes or saprophytes. While they are invaluable decomposers of organic material, saprobes can also cause food spoilage and destroy wood products. During the American Revolution (1775-1783), more British ships were destroyed by wood-digesting saprobes than by enemy attack. Some saprobes even grow in aviation fuels, where they breakdown the fuels, destroying their usefulness.

Some fungi also form highly specialized relationships with other organisms (see Symbiosis). For example, the roots of most plants develop a mutually beneficial association with fungi to form mycorrhizae. Mycorrhizae greatly increase the nutrient-absorbing capacity of the plant root—the fungus absorbs minerals from the soil and exchanges them for organic nutrients synthesized by the plant. Fungi also form mutualistic associations with various animals. For example, leaf-cutting ants cut pieces of leaves and bring them into their underground nests, where they feed them to certain fungi. These fungi primarily live in ant nests, and the ants eat nothing but the fungi. Some termites and wood-boring beetles use fungi to break down the cellulose in wood, making the wood easier for the insects to digest. Plant parasites such as rusts invade plant cells via specialized structures called haustoria that absorb nutrients from the cell.

III FUNGI STRUCTURE



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Structure of a Fungus

Fungi are made of filamentous tubes called hyphae. In many species, perforated walls, or septa, divide the hyphae into cells containing one or two nuclei. Protoplasm flows through the opening in the septa to provide the cells with nutrients, which are stored in the hyphal walls as glycogen. Hyphae elongate from the tip. The entire mass of hyphae is collectively called the mycelium.

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With the exception of one-celled species, most fungi are composed of threadlike tubular filaments called hyphae. Each individual hypha is surrounded by a fairly rigid wall usually made of chitin—the same material that forms the exoskeletons of insects. Hyphae that are partitioned by dividing cross walls are called septate hyphae, and hyphae without cross walls are called nonseptate, or coenocytic, hyphae. Fungal cells contain cytoplasm, which is a mixture of internal fluids and nutrients. Cytoplasm flows freely within the hyphae, providing nutrients wherever they are needed.

Hyphae grow by elongation at the tips and by branching to form an interwoven mat known as the mycelium. As the mycelium develops, it may produce large fruiting bodies or other structures that contain reproductive spores. Fruiting bodies are often the most visible structure of a fungus, usually growing above the soil or other surfaces so that the spores can be dispersed by air currents or other mechanisms. In contrast, the mycelium is usually hidden beneath the surface of the plant, animal, or other material it is decomposing. For example, a mushroom mycelium is typically buried beneath the soil surface, while its fruiting body, the familiar umbrella-shaped structure, sprouts from the ground.

IV REPRODUCTION



Richard Packwood/Oxford Scientific Films

Puffball Mushroom Releasing Spores

Many fungi reproduce by releasing vast numbers of spores, often numbering in the billions or trillions. The spores, which develop in the fruiting body of the mushroom, are minute spherical structures that contain a small amount of protoplasm. Mushrooms, such as the puffball, produce spores both sexually and asexually.

Richard Packwood/Oxford Scientific Films

The wide variety of fungi demonstrate many reproductive methods. In general, most fungi reproduce by making tiny spores. Fungi typically produce large numbers of spores. A giant puffball, for example, produces an estimated 7 trillion spores.

Fungi typically follow a reproductive cycle that involves the production of sexual spores. These spores contain one or more nuclei and are usually haploid—that is, their nuclei contain one set of chromosomes. When environmental conditions are favorable, the spores germinate and develop into a mycelium that produces fruiting bodies with enormous numbers of sexual spores, which repeat the reproductive cycle. Some fungi produce asexual spores directly from hyphae, which then germinate to produce additional mycelium. The mycelium spreads rapidly, aiding the fungus in dispersal and colonization.



Life Cycle of a Mushroom

Most mushrooms undergo a complex reproductive cycle in which they produce reproductive spores that undergo sexual reproduction under proper environmental conditions. Mushrooms belong to the phylum Basidiomycetes,

named for the tiny, club-shaped structures called basidia that these fungi use to produce spores. The basidia line the undersides of a mushroom cap on thin gills that radiate from the mushroom's center.

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In the reproductive cycle of mushrooms, the mycelium contain hyphae of two mating types, sometimes called plus and minus strains, with no obvious anatomical differences distinguishing them. If plus and minus strains of hyphae fuse, sexual reproduction begins. Initially the nuclei of the two hyphae remain separate, producing an intermediate stage called the *dikaryon*, meaning "two nuclei." The dikaryon stage can last from weeks to years, depending upon the species. The two nuclei in the dikaryon eventually fuse to produce a diploid cell—that is, a cell that contains one nucleus with two sets of chromosomes. This cell immediately undergoes meiosis, a type of nuclear cell division that produces offspring with half the genetic material as the parents. Meiosis usually produces four genetically unique haploid spores and the reproductive cycle begins again. This population of genetically different spores has a better chance of surviving environmental changes, such as disease or temperature changes, that may wipe out an entire population of genetically identical spores.

Many fungi can reproduce by the fragmentation of their hyphae. Each fragment develops into a new individual. Yeast, a small, single-celled fungus, reproduces by budding, in which a bump forms on the yeast cell, eventually partitioning from the cell and growing into a new yeast cell.

V CLASSIFICATION OF FUNGI

Scientists have long disagreed about how to classify fungi, and the classification systems are still developing. The first description of fungi was published in 1729 by Italian botanist Pier Antonio Micheli. Fungi were initially classified in the Plant Kingdom, and the field of fungus study, or mycology, developed as a branch of botany. Recognition of the unique characteristics of fungi led mycologists to establish a separate kingdom, Kingdom Fungi, in the late 1960s. More recently, some mycologists have noted that some organisms, such as slime molds, downy mildews, and water molds, have characteristics that place them in the Kingdom Protista rather than the fungi. Unlike true fungi, some slime molds have a mobile, multinucleate feeding stage similar to amoebas. Downy mildews and water molds produce motile cells for part of their life cycle, have hyphal walls that lack chitin, and make an egg cell and sperm nuclei. Some scientists have proposed that downy mildews and water molds deserve to be classified in a separate kingdom, called Kingdom Stramenopila.

Fungi are classified primarily by the type of spores and fruiting bodies produced. Many mycologists divide the Kingdom Fungi into four main phyla: Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota. A fifth phylum, Deuteromycota, is used by some taxonomists for fungi that typically produce only asexual spores.

The phylum Chytridiomycota, commonly called Chytrids, includes approximately 800 species that are found in aquatic (freshwater and marine) or moist habitats. Chytrids are among the smallest and simplest fungi. Most have a central body with small tubelike extensions, while others produce a small network of hyphae. Chytrids develop a structure called a sporangium that has motile spores equipped

with a posterior flagellum, a long, whiplike tail that aids in locomotion. Chytrids grow as saprobes in damp soils and water, or as parasites of plants, animals, algae, protists, and other fungi. Some do not require oxygen and live only in the guts of plant-eating animals, where they break down material containing cellulose and other compounds. Because chytrid spores are motile, some mycologists have classified them in the Kingdom Protista.



Black Bread Mold

A member of the phylum Zygomycota, this black bread mold growing on a piece of stale bread shows the mycelium, or interwoven filaments that make up the vegetative portion of the fungus. The small dark spots are the fruiting bodies, or sporangia, from which the spores are released.

John Cooke/Oxford Scientific Films

The Zygomycota include approximately 900 terrestrial species, including many important decomposers, mycorrhizal fungi, and parasites of spiders and insects. One of the most common zygomycetes is black bread mold, often found on bread, fruit, and other foods. The fungus looks like a fuzzy growth with tiny black dots at the tips of the fuzz. The black dots are sporangia growing at the ends of special hyphae. The sporangia produce asexual, nonswimming spores called sporangiospores. Zygomycetes reproduce sexually by forming thick-walled zygospores.

The largest group of fungi, with around 50,000 known species, is the Ascomycota, or sac fungi. This group includes yeasts, lichens, morels, cup fungi, truffles, and a number of plant parasites such as powdery mildews. Named for the sexual spores produced inside saclike cells called *asci* (singular, *ascus*), Ascomycota also may produce very fine, almost powdery asexual spores called *conidia*. Certain Ascomycota such as cup fungi produce fruiting bodies with sexual spores on their upper surface, while others, including the truffles, produce sexual spores inside tuber-like fruiting bodies that develop underground.

Ascomycetes are used to produce Camembert and Roquefort cheeses. The slight grittiness in these cheeses is due to conidia being crushed between the teeth. The mold ergot, which infects the flowers of rye and other grains, produces toxins that can poison humans and other animals that eat the infected grain. The yeast *Candida albicans* is a common pathogen of humans, causing such ailments as oral thrush and vaginal yeast infections. In people with weakened immune systems, this yeast may spread widely throughout the body and become life threatening.



Sulfur Fungus

A member of the phylum Basidiomycetes, the sulfur fungus is one of the largest of the edible fungi, reaching a width of several meters and a weight of several kilograms. It typically grows on trees, sometimes at heights that make harvesting these fungi difficult.

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The Basidiomycota, also known as club fungi, include around 25,000 species of mushrooms, puffballs, bird's nest fungi, jelly fungi, rusts, smuts, and shelf and bracket fungi. This division contains important plant parasites, mutualists, and saprobes, including decay fungi that cause brown rot and white rot of wood. These fungi are named for their specialized, club-shaped reproductive cells, called basidia, which form spores called basidiospores. Basidia may line gills or tubes on the underside of fleshy fruiting bodies, which consists of a stalk and cap—the familiar components of most mushrooms. Certain Basidiomycota produce spores inside tuber-like underground fruiting bodies, called "false truffles."

Many basidiomycetes are saprobes, which play a vital role in the decomposition of litter, wood, and dung. A number of mushrooms are good to eat, such as boletes and chanterelles, both of which are highly prized for their distinct flavor. Other mushrooms are well known for their poisonous qualities, including the death cap (*Amanita phalloides*). Some, such as the liberty cap (*Psilocybe semilanceata*) and the fly agaric (*Amanita muscaria*), are well known for their hallucinogenic properties. Smuts—such as *Ustilago*, which attacks corn, and stinking smut (*Tilletia*), which attacks wheat—are common basidiomycetes that invade flowering plants, especially cereal grasses, and cause serious economic loss. Rusts, such as *Puccinia*, which attacks wheat, invade plant cells of agricultural crops and forest trees, causing millions of dollars in losses each year.

The Deuteromycota, or imperfect fungi, comprise about 25,000 species, many of which do not have a defined sexual cycle. They typically reproduce asexually by spores called conidia on specialized hyphae called conidiophores. The deuteromycetes include many molds, some of which are important to humans. *Penicillium*, the mold used to develop the first antibiotic, is sometimes classified in the Deuteromycota. On the other side of the ledger, the deuteromycetes also include organisms such as ringworm that are serious animal and plant pathogens.

VI USES OF FUNGI



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Chanterelle Mushroom

The chanterelle mushroom is one of the most popular edible mushrooms. Harvested since Roman times throughout Europe, it is prized for its nutlike flavor. Unlike some species of edible fungus, larger specimens of chanterelles provide a better texture and flavor than do smaller specimens.

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Fungi have been used as a food source since the beginning of recorded history. Mushrooms add flavor, texture, and nutritional value to many dishes. In North America in recent years, a variety of mushrooms have gained popularity, including portabella, cremini, oyster, morel, chantarelle, wood or tree ear, truffle, matsutake, and shiitake.



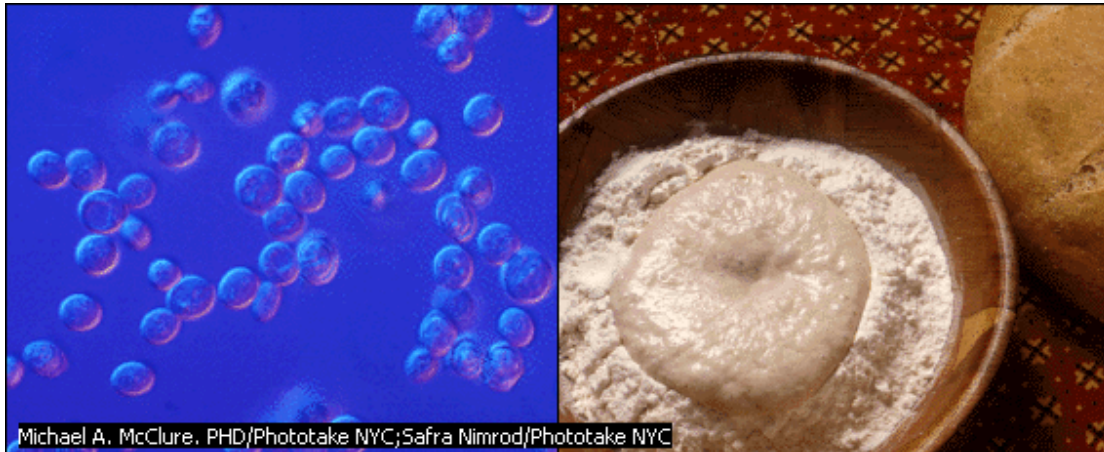
Adam Woolfitt/Woodfin Camp and Associates, Inc.

Truffle Hunting

A farmer leads a pig in a search for truffles in France. Though the fungus grows underground, its scent is so strong and distinctive that dogs and pigs can be trained to detect it.

Adam Woolfitt/Woodfin Camp and Associates, Inc.

Truffles—tuber-like, fleshy fungi with a characteristic taste and aroma—are highly prized by gourmet chefs. Harvested most commonly in France and northern Italy, truffles are collected with the aid of trained dogs or pigs that use scent to hunt these fungi hidden beneath the soil. The price for truffles in Europe may reach as high as \$500 (U.S.) per pound in some years.



Michael A. McClure. PHD/Phototake NYC;Safra Nimrod/Phototake NYC

Bread Yeast

Bread yeast, *Saccharomyces cerevisiae*, or baker's yeast, a type of fungi, reproduces by a process called budding. Bread yeast causes bread to rise by releasing carbon dioxide, which gets trapped in the dough. Here, microscopic yeast (left) have a macroscopic effect (right) on bread dough.

Michael A. McClure. PHD/Phototake NYC;Safra Nimrod/Phototake NYC

Other fungi are used in the manufacture of foods. Yeast, for example, is added to fruit juice, which it ferments to produce wine. Yeasts also are used in the manufacturing of beer, and they are added to dough to make bread rise, producing more volume and a lighter texture in the final baked product. Certain molds are used to ripen cheeses, such as Brie, Camembert, and the characteristic blue-veined Roquefort. In Asia, fungi are added to soybeans and allowed to ferment to make several food products—soy sauce is made with the mold *Aspergillus*, and tempeh is made with the black bread mold *Rhizopus*.



Andrew McClenaghan/Science Source/Photo Researchers, Inc.

Penicillium Mold

Penicillin is an important antibiotic derived from the mold *Penicillium notatum*, pictured here. Penicillin is effective against a wide range of disease-causing bacteria. It acts by killing bacteria directly or by inhibiting their growth.

Andrew McClenaghan/Science Source/Photo Researchers, Inc.

Many fungi also produce biologically active compounds that are useful in manufacturing. These compounds include alcohols—such as ethanol and glycerol produced during fermentation—and plant growth regulators—such as gibberellic acid, which is used in the promotion of plant and fruit development. Fungi are extremely important in the production of antibiotics; for example, penicillin, griseofulvin, cyclosporine, and cephalosporin are used to fight bacterial and fungal diseases worldwide.

Fungi are becoming an increasingly important tool in cleaning the environment. The accumulation of pesticides and other chemicals in the environment is destroying many ecosystems, and placing many animal and plant species at risk. A number of fungi are used in bioremediation, in which the fungi are mixed with polluted water or soil, where they decompose the organic material in pollutants and, in the process, detoxify them. Fungi employed in this effort include many that are commonly found in soils, such as *Aspergillus*, *Fusarium*, *Rhizopus*, *Mucor*, *Penicillium*, and *Trichoderma*. Fungi also have been used successfully to control insects, fungus pathogens, roundworms, and other organisms that cause damage and disease to agricultural crops.

VII HARMFUL FUNGI



Corn Smut

The corn smut is a parasitic fungus that attacks the ears, stalks, and tassels of corn. Large, unsightly mycelial, or fungal, masses develop that eventually produce large quantities of black spores. Occasionally smut galls, or swellings, are produced, which are used as food in some areas of Central and South America.

Gilbert Grant/Photo Researchers, Inc.

Fungi cause about 100,000 diseases of plants, including about 70 percent of the major crop diseases, resulting in an economic loss of billions of dollars each year. These plant pathogens cause extensive disease to seeds, seedlings, mature plants, and aging plants, resulting in decreased growth and reproduction of crop plants. Fungi also attack forest trees and wooden structures.

A number of fungi cause diseases in humans and other vertebrates. In general, these fungus infections, or mycoses, develop slowly, recur more frequently than bacterial infections, and do not produce a lasting immunity in the body. A mycosis is classified in one of two groups, depending on the part of the body that is infected. A dermatomycosis is an infection of the skin, hair, or nails, such as ringworm or athlete's foot. These infections rarely progress to the internal organs. Most respond well to medication, although treatment may take several weeks.



David Thompson/Oxford Scientific Films

Fly Agaric Mushroom

The brightly colored fly agaric mushroom is a deadly poisonous mushroom. Containing ibotenic acid and a number of other organic poisons, the fly agaric can cause severe damage to the central nervous system, blood vessels, kidneys, liver, and muscles. Symptoms, which may not become apparent for 8 to 12 hours or longer, include nausea, vomiting, and severe diarrhea and can lead to coma and death.

David Thompson/Oxford Scientific Films

A systemic mycosis, which is an infection of the entire body, is typically more serious and can be fatal for individuals whose immune system has been weakened by diseases such as acquired immunodeficiency syndrome (AIDS) or cancer. Fungal infections are typically spread by spores that enter the body through inhalation or through an opening in the skin. Some infections are passed from animals to humans or between humans. A few drugs are effective at treating systemic infections, but because treatment may last for several months to years to prevent relapse of the infection, these drugs often cause toxic side effects.

Fungi cause a number of human respiratory diseases. Coccidioidomycosis is caused by the yeast *Coccidioides immitis*. Although typically contracted by the inhalation of dust containing yeast spores, the fungus may also be introduced through the skin from infected soil. Initial symptoms may resemble the flu, with fever, cough, and possibly a skin rash, and the infection usually runs its course without specific treatment. In rare cases, the fungus penetrates internal tissues, such as the bones, joints, and brain, producing tumors that later form abscesses or ulcers. No treatment is available that can halt the course of this form of the disease.



Nigel Cattlin; Holt Studios International/Photo Researchers, Inc.

Powdery Mildew on a Plant

Mildew is a parasitic fungi. The powdery mildew shown here often attacks the leaves of plants, usually those in shaded areas in humid regions. The white spores of the fungi produce a powdery pattern on the leaves and cause the leaves to curl and wither.

Nigel Cattlin; Holt Studios International/Photo Researchers, Inc.

Histoplasmosis is caused by the yeastlike fungus *Histoplasma capsulatum*, which grows in pigeon, bat, and chicken droppings. Contracted by the inhalation of dust from animal droppings, by ingestion, or through the skin. The fungus causing histoplasmosis lives as a parasite in certain tissue and blood cells of the infected person. An infection in the respiratory system is similar to tuberculosis—small spots form in the lungs—although these lesions heal on their own. A progressive form typically invades the bone marrow and is rapidly fatal.

Aspergillosis is an infection of the skin, nasal sinuses, and lungs or other internal organs caused by molds of the genus *Aspergillus*. The disease, contracted by the inhalation of spores, occurs most often among agricultural workers. Itching and pain are frequent symptoms, and if scratching is prolonged, the skin may thicken and become gray or black. A virulent type of pneumonia is caused by the yeastlike fungus *Pneumocystis carinii*, particularly prevalent in people with compromised immune systems, such as AIDS patients.

Mycotoxins are poisons produced by fungal growth in cereals, nuts, fruits, and vegetables. More than 100 species of fungi produce these toxins. The most common mycotoxin is aflatoxin, produced by *Aspergillus flavus* and *Aspergillus parasiticus*. Commonly found on corn, peanuts, and tree nuts, the toxin also can be transmitted to humans through the milk, meat, or eggs of animals fed contaminated grains. Aflatoxin is the most potent carcinogen, or potentially cancer-causing agent, yet discovered. Other mycotoxins include trichothecenes and zearalenone, compounds known to injure the intestines, bone marrow, lymph nodes, spleen, and thymus. They are produced by species of *Fusarium* that grow on grain, straw, or hay stored while damp. Occasionally, circumstances prevent the harvesting of grains during the autumn, and the grains lie dormant in the damp fields until they are harvested in the spring. These grains are especially vulnerable to trichothecenes and zearalenone contamination. A large outbreak of trichothecenes contamination occurred in Russia in early 1944 among hungry peasants who had been searching the winter fields for unharvested wheat and millet.

Scientific classification: Fungi are classified in the Kingdom Fungi, also known as the Kingdom Mycetozoa. The kingdom has five main phyla: Chytridiomycota, Zygomycota, Ascomycota, Basidiomycota, and Deuteromycota.

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