The Fungi

The organisms commonly known as fungi (sing. fungus) are a tremendously diverse group found in virtually all habitats. Included here are forms commonly referred to as mushrooms, morels, truffles, molds, mildews, yeasts, earthstars, stinkhorns, rusts, smut and bracket or shelf-fungi to name few. Because of their diverse nature, the fungi are a difficult group to define. Perhaps the best way to describe these fascinating creatures and introduce them to you is to consider the characteristics that most of them share.

One of the distinctive features of most fungi is that they are composed of microscopic, walled, branched, thread-like filaments called hyphae (sing. hypha). These filaments are the basic structural and functional units of most fungi. Hyphae grow almost exclusively at their tips and are capable of rapid elongation. Collectively, all the hyphae of a particular fungus comprise its body or so-called mycelium (pl. mycelia). Depending upon the species involved as well as environmental conditions and availability of a food source, this mycelium maybe small or massive, sometimes even spreading over acres of land and weighing in excess of several tons. Generally speaking, however, the mycelium of a fungus is out of view and rarely noticed, as it is embedded in whatever substrate the fungus grows on. In most cases the presence of a fungus becomes apparently only when bread goes moldy or forgotten fruits and vegetables pushed to the backs of refrigerator bins become covered with fuzzy green, white, yellow or black growth. Likewise, the mushrooms that suddenly appear on the ground and the shelf-like fungal growths that emerge from living and dead trees are simply reproductive structures of various fungi and not in themselves individual organisms. They, like the mycelia from which they arise, are all composed of hyphae.

Aside from reproductive structures, probably the most complex structures produced by fungi are rhizomorphs. Commonly known as shoestrings or mycelia cords because of their appearance, these root-like structures consist of closely packed hyphae often surrounded by a thin, rind-like layer. Rhizomorphs are produced by a variety of wood-rotting fungi as well as few species that attack the roots and trunks of living trees. These black, white or yellow to orange strands often can be found growing beneath the bark of dead or dying trees or on decaying logs. Rhizomorphs can reach great lengths in some species and perform a variety of important functions for the fungi that produce them, including the discovery and development of new food sources, the movement of water and nutrients and even survival of adverse conditions such as drought, fire and freezing temperatures.

Here it should be noted that hyphae are not always formed by all fungi. Some species have a tendency to grow as hyphae under certain conditions but as single cells under other conditions. Such is the case, for example, in certain species that attack humans and other animals. Outside their hosts such forms produce hyphae, but in host tissues they tend to exist as single cells. Still other fungi grow almost exclusively as single cells under all conditions. These are the so-called yeasts that are important to humans in a variety of ways that will be discussed later. Yeasts reproduce asexually by either binary fission or budding, both of which are very effective forms of reproduction. In fission, the parent cell simply splits to form two smaller, but otherwise identical cells that then undergo a period of growth before undergoing fission themselves. In budding, a small outgrowth called a bud begins to develop on the surface of a parent cell. The bud increases in size and them pinches off from the parent cell to become a new, independent, single-celled organism. Multiple buds may arise simultaneously from the same parent cell and buds may even produce buds.

A second characteristic shared by almost all fungi is the production of microscopic

reproductive units known as spores. A spore is basically a tiny fragment of a fungus surrounded by a wall and containing at least one nucleus as well as a basic complement of essential cellular organelles. As will be discussed later, spores may arise as either the result of sexual or asexual reproduction. They tend to be produced in tremendously large numbers and are designed for dissemination by wind, water and, in some cases, animals. In addition to their importance in the spread of fungi to new habitats, some types of spores result in the formation of one or more tiny outgrowths termed germ tubes that develop into hyphae. Whether or not these hyphae give rise to a successful new mycelium depends upon many factors including pH, moisture and temperature and whether or not the hyphae contact a suitable food source. Fortunately for us, most spores do not give rise to successful mycelia. If they did, we would be overrun by fungi!

Perhaps the most familiar spore-producing structures produced by fungi are mushrooms. A typical mushroom is umbrella-like, consisting of a central stalk and a cap. The spore-producing parts of a mushroom line the thin flaps of tissue known as gills that hang down from the underside of the cap. When mature, the spores are shed from the gills and either fall to the ground or are carried away by wind or water.

As alluded to above, an additional characteristic that most fungi exhibit is the ability to reproduce both asexually and sexually, through not necessarily at the same time. Here the term sexual reproduction simply means that the events of nuclear fusion (fertilization) and meiosis, a special type of nuclear division, take place during the formation of certain types of spores. These so-called sexual spores are genetically different from the parents (or parent if only one organism is involved as is often the case in fungi) and, therefore, have the potential to give rise to genetically different offspring. In asexual reproduction, on the other hand, there is no genetic recombination and

unless a mutation occurs, all the resulting spores will give rise to individuals that are identical to the parent fungus. Such individuals are said to be clones of the parent.

Fungal spores, though all microscopic, come in an incredible variety of sizes, shapes and colors. Some are round, others oval to pear-shaped and still others long and thin and either straight, curved, wavy or spirally coiled. Some consist of just a single cell while others are multicellular in their construction. Those of one well-known species resemble miniature snowshoes when viewed microscopically while those of a few species are reminiscent of tiny insects of one kind or another. In some cases various types of appendages protrude from the spore surface. These appear to help some spores float on water. If you examine with a microscope some of the foam that accumulates in the eddy of a stream or along the waterline at a beach, you may be lucky enough to find some of these types of spores. While most spores are transparent when viewed with a light microscope, others are pigmented and may appear black, brown, yellow, orange or even reddish in color.

In spite of the diversity found among fungal spores, those produced by any one species are highly consistent and, for this reason, spore characteristics are very important in the identification of fungi. In fact, most of the major groups of fungi are named on the basis of the sexual spores they produce.

In the few fungi that lack the ability to form spores, reproduction occurs by the fragmentation of the mycelium. This form of asexual reproduction also is available to species that produce spores and is employed routinely when growing fungi on artificial media in the laboratory. By simply removing a small piece of the mycelium and transferring it to fresh media, it is possible to grow many species for seemingly unlimited periods of time under laboratory conditions.

Without exception, all fungi are heterotrophs and exhibit absorptive nutrition. This simply means that they can not produce their own food as can green plants and a few specialized bacteria and instead must absorb it from their surroundings. As a result, fungi exist as either saprobes growing on the remains of dead organisms or as parasites that obtain nutrients from living hosts. While the vast majority of fungi are saprobes, many are parasites of plants and animals and a few even attack other fungi. Ultimately, whether a particular species is a saprobe or a parasite depends, of course, upon its genetic makeup. Some species are capable of growing as either saprobes or facultative parasites depending upon the circumstances. Those that require a living host in order to survive are called obligate parasites. Still other species tend to form so-called mutualistic relationship with other organisms. In this type of interaction the fungus still obtains food from its partner as in a parasitic relationship, but in return provides significant benefits to its partner. Examples of mutualistic relationships can be found in lichens which are combinations of fungi and algae and mycorrhizae which are relationships between the hyphae of certain fungi and the roots of plants. Mycorrhizae, it turns out, are extremely important in overall plant health and, in some instances, help to determine where plants can grow.

The final characteristic that all fungi share is the production of true nuclei. This fact needs to be emphasized in order to separate fungi from bacteria. Except for the fact that bacteria lack true nuclei, as a group they exhibit all the other characteristics described above including heterotrophic life styles, production of spores, reproduction by both sexual and asexual means and, in a few species, the formation of filaments that resemble hyphae.

The scientific study of fungi is called mycology and those individuals who study fungi are known as mycologists. Thus far mycologists have identified about 70,000 different species of fungi,

but the general consensus is that there are hundreds of thousands of others that remain to be discovered. As noted already, most fungi are saprobes and can be found in virtually all habitats where, as group, they have the ability to grow on almost any organic material. Saprobic fungi are, however, most important in nature as decomposers of dead plants. Fungi are the principal organisms that decay cellulose and lignin, the major components of plant cell walls and, were it not for activities of fungi, much of the Earth's surface by now would be covered completely by the remains of dead plants, most notably leaves. The breakdown of the remains of dead plants also returns essential elements such as carbon and nitrogen to the environment so they can be used by other plants. Fungi therefore play an essential role in nutrient cycling in ecosystems.

Aside from dead plant tissues found in nature, other common substrates on which fungi grow that you are likely to encounter are animal excrement, the remains of dead animals, meat products, breads, fruits and vegetables, leather shoes, belts, jackets and purses, shoe polish, roofing shingles, paint, plaster, the soap film that accumulates on shower curtains and the grout between bathroom tiles, and the remains of soft drinks and coffee left in forgotten glasses or cups. While you probably won't see them, a variety of different fungi also can grow on dirty rugs, carpets, furniture and draperies if a little moisture is available. Additionally, some fungi grow on dirty filters in air conditioning and heating systems. These "indoor fungi" often produce spores that cause allergies in individuals who inhale them and are many times important components of so-called "sick-building syndrome."

Because of their abilities to decay plant cell walls, fungi pose serious problems for all sorts of wood products including lumber, landscape timbers, railroad ties and telephone poles. Virtually any wood product that gets wet eventually will be attacked and rotted by fungi. For this reason we

invest tremendous amounts of time, effort and money to see that lumber is properly painted or otherwise sealed to prevent it from becoming wet. In addition, various types of chemical preservatives that are toxic to fungi are used to treat wood products that routinely are exposed to the elements.

Aside from their activities as decomposers, fungi are important to humans in a variety of other ways. Beneficial activities of fungi include the production of various chemicals including certain steroids, organic acids, enzymes, ethyl alcohol, various antibiotics and other medically important compounds and certain plant growth hormones. Of these compounds, the most widely used is, of course, ethyl alcohol, a product that is formed along with carbon dioxide when yeast ferment sugars. The strains of yeasts used to produce alcohol are selected on the basis of a variety of characteristics including their ability to produce large quantities of alcohol, but otherwise they are similar to the common "baker's yeast" that is available in dry packets at grocery stores. When these single-celled organisms are placed in water with a little sugar and flour they begin to ferment the sugar releasing bubbles of carbon dioxide that cause the dough to rise. When alcohol is the desired product, substrates containing high levels of sugar are used. The most famous of these is, of course, the grape juice that is used in the production of wine. However, juice from almost any fruit or other starch containing plant organ can be fermented. For example, bourbon is made from corn, beer from barley, rice or millet, sake from rice, rye from rye, and vodka from wheat, potatoes or corn. In some countries alcoholic concoctions are even made from the milk of various animals.

Of the many important antibiotics obtained from fungi, the most famous is, of course, penicillin which has saved untold numbers of human lives. First discovered in the late 1920s and subsequently developed commercially in the early 1940s, this chemical inhibits the growth of various

types of bacteria that cause infections in humans and other animals. Though various forms of penicillin are still used today, many bacteria have developed resistance to this drug. An example of another fungal product that has had a tremendous impact in medicine is cyclosporin. This compound can be used to suppress the immune response that often results in the rejection of transplanted organs. The availability of cyclosporin has helped to make transplant operations almost common place in the last few years.

A variety of different fungi are used either in the production of food items or eaten directly. Examples of so-called "fermented foods" produced by inoculating certain grains such as rice, wheat or soybeans with various fungi include Miso, Tempeh and Sufu. Soy sauce also is a fungal product. Additionally, many types of cheeses are made using fungi. Examples include Roquefort, Camembert, Brie and Danish blue. In the case of blue cheese, the greenish-blue material visible when a package is opened is a fungus belonging to the genus *Penicillium*, the same type of fungus from which the famous antibiotic was isolated. Perhaps one of the most interesting fungal products eaten by humans is "cuitlococh e," sometimes marketed in this country under the name of "maize mushrooms". This material is popular in Mexico and consists of fleshy, gall-like growths produced on ears of corn that are infected by *Ustilago maydis*, a common plant pathogenic smut fungus. These growths consist of both fungus hyphae and spores as well as host tissues.

The reproductive structures of a variety of different types of fungi are used as food in many parts of the world. In some regions these reproductive structures, mostly commonly those of mushroom fungi, are collected in nature and sold fresh in market places. However, a number of different species have been "domesticated" and now are grown commercially, some on a very large scale. In North America the mushroom most likely to be found in the fresh vegetable section of your

favorite grocery store is one of the so-called "meadow mushrooms" belonging to the genus *Agaricus*. This is the same mushroom that comes thinly sliced and spread over pizzas. It also is canned and used in the production of mushroom soup. *Agaricus* first was cultivated in France in the 1650s and by 1870 commercial production had spread to the United States, principally in and around Philadelphia, PA. Historically, *Agaricus* has been grown on a mixture of composted horse manure and wheat straw, though modern growers are experimenting with other substrates as well. In recent years, other species of mushrooms have begun to appear in supermarkets and restaurants in North America and include the shittake, oyster, straw and enokitake mushrooms as well as *Auricularia*, the so-called "ear fungus" that is popular in Chinese dishes. Many of the species noted above have been grown for centuries in China and Japan and, for those of you who are interested, it is now possible to purchase small "mushroom kits" and grow some of these species at home.

The most highly prized edible fungi are the morels and European truffles. Morels, commonly known as sponge-mushrooms because of their distinctive appearance, can be found in many parts of the United States for a period of a few weeks each spring. Searching for them is a popular leisure activity in many areas and avid morel hunters have been known to schedule vacation times to coincide with morel season. Although morels sometimes can be elusive, a lucky individual or, more typically, someone with a secret collecting area, often can find large numbers of these delicious specimens in a matter of a few minutes. In recent years morels have been produced in culture and perhaps it won't be too long before they are available on a commercial basis. Truffles, on the other hand, have not been cultivated. The small potato-like reproductive structures of these fungi are produced underground in the vicinity of oak trees with which these fungi are mycorrhizal. For centuries truffles have been hunted in France and Italy, often with pigs that, by the way, like to eat

truffles themselves, and, more recently, with specially trained dogs. Of all the fungi that are eaten, truffles are the most valuable, sometimes selling for hundreds of dollars a pound. Efforts currently are under way to produce the European truffles into the United States.

At this point it should be noted that there are a variety of other wild mushroom and mushroom-like fungi whose reproductive structures are edible. However, a number of species are poisonous with symptoms ranging from upset stomach to death. For this reason you should never eat a wild mushroom unless it has been identified and pronounced safe by someone who is an expert on the identification of fungi. Some of the most poisonous mushrooms belong to the genus *Amanita*. Like most other mushroom fungi, members of this genus tend to be mycorrhizal with trees and produce their typically large and often attractive reproductive structures near or under their tree partners. The most poisonous of all fungi is *Amanita phalloides*, commonly called either the "death cap" or "death cup." This mushroom tastes good, but some 12 hours or so after it has been eaten the unsuspecting victim gets violently ill and even with the best medical treatment usually dies some 2-3 days later as a result of damage done to the liver and kidneys.

A few mushrooms produce hallucinogenic effects when eaten. The best known examples are members of the genus *Psilocybe*. These typically small and rather nondescript mushrooms develop on either cow or horse manure or on pasture soils enriched with these materials. Consumption of these mushrooms produces effects similar to those of LSD and in the United States these mushrooms are considered by law as controlled substances. Historically, *Psilocybe* mushrooms have been used by certain of the native peoples of Mexico and South America in their religious ceremonies. Another well-known hallucinogenic fungus is *Amanita muscara*. Consumption of this mushroom can be traced as far back as the time of the ancient Egyptians. Additionally, it appears that certain Nordic

tribes including those known as Vikings may have used this mushroom to produce a sort of drunken frenzy, hence the name "madman's mushroom" sometimes given to this fungus. *Amanita mascara* also is known as the "fly mushroom" because of the fact that it contains a chemical that kills flies and various other insects. In the past, people in various parts of the world would soak these mushrooms in milk or some other liquid and then place the material at various places in and around their homes. Flies that fed on the material died. *Amanita muscara* is, by the way, a large, beautiful mushroom with a white stalk and a red cap covered with white, scale-like patches of tissue. You have probably seen it depicted numerous times in various forms of artwork.

Aside from the fact that fungi decay things we don't want them to, many of them are potentially harmful to us in a variety of other ways. For example, some grow on various types of edible grains and nuts and, in doing so, produce a group of toxic compounds called aflatoxins. Foods contaminated with these chemicals pose serious health risks both for us and our animals. Consumption of moldy grains and feeds containing high levels of aflatoxins can cause death. When smaller amounts of these chemicals are administered experimentally over extended periods of time they have been shown to cause cancer in all animals tested. In fact, aflatoxins are among the most highly carcinogenic (cancer-causing) compounds known. Fortunately, food items most at risk for aflatoxin contamination including corn and peanuts are screened to make sure that they are free from dangerous levels of these compounds. In addition to aflatoxins, a variety of other potent fungal toxins are known. At least one of these reportedly has been used as a biological warfare agent, possibly in both Vietnam and Afghanistan.

A few fungi are capable of causing diseases in animals and humans. The most common are those that grow on skin causing so-called ringworm infections. A few of these fungi appear to be

virtually obligate parasites of humans, cycling from one person to the next by means of spores on items of clothing, sheets and blankets, theater seats, hair brushes and barber's clippers. Other ringworm fungi can be contracted from various animals, quite often cats, or even directly from the soil. Ringworm of the scalp is common in children, while adults tend to suffer from ringworm of the foot (athlete's foot) and ringworm of the groin (Jockey itch). Interestingly, one of the most effective drugs used to treat ringworm infections is a fungal product by the name of griseofulvin that is obtained from a species of *Penicillium*.

In addition to fungi that grow on skin, there are some others that can grow inside humans and animals. Some of the infections they cause can be life threatening even with the most modern medical treatments. Because these types of fungi usually enter the body as spores that are inhaled, infections typically begin in the lungs. However, a few fungi that are capable of infecting humans and animals can gain entrance through the eye or through cuts and abrasions or puncture wounds caused by thorns or wooden splinters. Probably the most common fungal respiratory infection in United States is histoplasmosis. This disease is most prevalent in inhabitants of the central and southeastern states. The fungus responsible grows on the excrement of bats and various birds such as starlings, pigeons and chickens. People who work with chickens and those who go in caves where bats roost tend to be at greatest risk of infection. Once established in the lungs, the fungus may spread to other parts of the body. When it does, death often occurs.

Although anyone can get a serious fungal infection, most healthy individuals really don't have much to worry about in this regard. However, people with physiological disorders such as AIDS or diabetes and those who are taking immunosuppressive drugs or undergoing chemotherapy for cancer can be at great risk of infection even by common, everyday fungi that are not considered

to be aggressive human pathogens. Along these lines, women who take birth control pills are likely to suffer from so-called yeast infections caused by *Candida albicans*, a yeast-like fungus that is a normal part of the human body's microflora. Physiological changes caused by the chemicals in these pills can lead to excessive growth of this organism that results in vaginal irritations. Abnormal growth of this species also can occur in the human mouth and on fingernails. Fingernail infections can be very difficult to get rid of and often permanently disfigure nails.

Species of fungi that attacks wild and cultivated plants cause many problems for humans. Virtually every known plant species is attacked by one or more species of fungi. Examples that pose serious problems on plants that are grown for either food, fiber, lumber or aesthetic value include rusts, smuts, powdery mildew and downy mildews to name a few. The damage done to a particular host plant by a specific pathogen varies greatly and depends upon many factors. However, in some cases entire populations of plants can be decimated. Because of this, much time, effort and money are expended in trying to protect plants from fungi. Various agricultural practices such as crop rotation, sanitation and quarantines are important in this regard, but we rely most heavily upon the use of hybrid plants that have been bred to be resistant to specific fungi and the application of chemicals known as fungicides. In recent years, many of the most effective fungicides have been removed from the market because of environmental concerns and, as a result, we are facing many new challenges relating to the control of fungal diseases of plants.

Over the course of history, fungal diseases of plants have contributed greatly to human suffering. Two of the most notable examples are late blight of potato and ergot of rye. The former disease destroyed the potato crops in Ireland in 1845 and 1846 and was responsible for the great famine that took the lives of about 1 million Irish citizens and led to the emigration of about 1.5

million others, principally to the United States. Late blight of potato is caused by *Phytophthora infestans*, a fungus that not only is capable of killing plants in the field, but also of rotting stored potato tubers. This was the first fungus scientifically demonstrated to be capable of attacking a healthy plant and inciting a disease. Realization of this fact led to the development of the science known as plant pathology. In contrast to *Phytophthora infestans, Claviceps purpurea,* the cause of ergot of rye, does little damage to its host. However, this fungus produces small, dark, resistant structures called sclerotia in the flowering head of the rye plants. These sclerotia contain some very potent LSD-like chemicals that are poisonous when consumed by animals and humans. Before this fact was discovered, no effort was made to remove these structures from rye grain before it was milled for flour. If significant numbers of sclerotia were present then bread made from the resulting flour was poisonous when consumed, causing a condition known as Holy Fire. During years when infection levels of rye where high, outbreaks of Holy Fire ravaged the inhabitants of parts of Europe where rye bread was a major source of nutrition. Among other things, the toxic chemicals from the sclerotia cause construction of blood vessels in the extremities of the body, causing a burning sensation. Poisoned individuals often underwent slow, agonizing deaths as they continued to consume contaminated bread, unaware that it was poisoning them. As a result of reduced blood flow, people often had their hands, arms, feet and even legs wither away and fall from their bodies at their joints. Consumption of smaller amounts of the toxic chemicals produces less drastic consequences, but may cause abortions and hallucinogenic effects.

In the United States some of our most serious plant diseases are caused by fungi that have been introduced into this country from other parts of the world. Two of the most famous are chestnut blight disease and Dutch elm disease. The fungus responsible for chestnut blight appears to have

been imported accidentally from Orient into New York in about 1900. From there it quickly spread throughout the entire range of the magnificent and extremely valuable American chestnut. To date, millions of mature trees have been killed by the disease and chestnut has been eliminated as a dominant forest species in this country. However, the roots of many chestnut trees are still alive and routinely send up shoots that may reach several feet in height before they are attacked and killed by the still present fungus pathogen. Dutch elm disease, so-called because it was first described on elms in Holland, first appeared in the U.S. in 1930s and has proceeded to decimate American elm, a beautiful and popular shade tree. The fungus that causes this disease is spread by a type of beetle that feeds on elm trees and lays its eggs beneath the bark. These eggs give rise to larvae that tunnel under the bark where the fungus produces its spores. Beetles that arise from the larvae become coated with these spores and spread them to other elm trees.

In summary, the fungi are a large and diverse group of organisms that are most important in nature as decomposers that recycle important nutrients. However, as noted in one popular mycology textbook, scarcely a day passes that each one of us is not harmed or benefitted either directly or indirectly by the activities of these creatures. Hopefully, the information included in the preceding paragraphs will give you a good idea of what these remarkable organisms are like. Now that you are aware of their characteristics, it is likely that you'll begin to notice more and more of these organisms.