Lecture 1: Diversity of fungi

What are fungi?

Although the term “fungus” (plural: fungi) has at least some meaning to the average person, few people know very much about these widely distributed, ecologically very important, and often exceedingly common organisms. Fungi are abundant in nature, but they are often overlooked, usually underappreciated, and sometimes misunderstood. Their sudden appearance and disappearance, their frequent association with decaying organic matter, their vivid colors, fantastic shapes, and in some instances their poisonous properties, often cause fungi to be regarded as objects of mystery and sometimes even to be associated with the supernatural. Actually, fungi are among the most important inhabitants of the natural world, and there is little question that everyone should have a fundamental knowledge of what fungi are, what they look like, where they occur, and what they do.

The formal study of fungi is termed “mycology,” and the scientists who consider at least some aspect of the biology or ecology of these organisms are known as mycologists. Mycology had its origin in botany, since fungi were once considered members of the plant kingdom. As a result, some of the terms that have been applied to the structures found in fungi are the same as those used for plants. In some ways, fungi are indeed similar to plants, but unlike plants they lack the green pigment chlorophyll. Thus, fungi cannot produce their own food through photosynthesis. Instead, they obtain their food by breaking down dead organic matter or, in some cases, by attacking and living on, or within, living plants, animals, or even other fungi.

Fungi that depend upon dead organic matter as their food source are called saprotrophs, while those that feed on living hosts are called parasites if the host is harmed but not killed and pathogens if their presence produces a condition (called a disease) that has the potential of resulting in the death of the host. The distinction between parasite and pathogen is not necessarily absolute, and a parasite may become a pathogen over time or under a different set of circumstances. In addition, some fungi form a symbiotic relationship with the roots of trees and other plants. This relationship, which is called a mycorrhizal association, is mutually beneficial to both the plant and the fungus. The fungus enables the plant to take up nutrients that would otherwise be unavailable, and the plant provides nutrition for the fungus. The majority of plants, including such common forest trees as eucalypts, oaks, maples, hickories, and pines, are involved in these associations. In some instances, the mycorrhizal association is so essential to the plant that the latter would not survive without its fungal partner.

Fungi play a very important role in regulating natural processes. For example, it has been estimated that in a year several million leaves fall to the ground in each acre (0.4 ha) of a temperate deciduous forest. These leaves do not continue to pile up year after year because various saprotrophic fungi break them down. For that reason, essential nutrients in the leaves are recycled to the soil. Fungi are also the major group of organisms responsible for wood decay.

Although the vast majority of fungi are terrestrial, a number are aquatic forms, and some of these are of considerable ecological significance. For example, in small, well-aerated streams, certain aquatic fungi play a key role not only in the decomposition of organic matter introduced into streams but also as intermediates in food chains involving many aquatic insects and other invertebrates.

Morphology of Fungi

The vegetative body of all but the simplest fungi consists of a system of very finely branched, microscopic, threadlike structures called hyphae (singular: hypha). An entire mass of hyphae making up a particular fungus is known as a mycelium (plural: mycelia). The mycelium typically occurs in soil, leaf litter, or decaying wood, where the individual hyphae obtain the nutrients and water the fungus needs to grow. After a period of growth and under favorable conditions of temperature and moisture, the mycelium usually produces one or more specialized fruiting structures, within or upon which the spores (literally the “seeds” of the fungus) are produced. The fruiting structure of a fungus is somewhat analogous to an apple on an apple tree, since it is the fruit of the mycelium. Most fruiting structures last for only a few days, but a mycelium may persist for a number of weeks, months, or even years.

As the fundamental structural unit of a fungus, a single hypha can be viewed as a thin, usually more or less transparent tube filled with cytoplasm and the various organelles typically associated with any eukaryotic cell. The tube itself represents the cell wall, and the latter is interrupted at places along its length by partitions, also referred to as cross walls or septa (singular: septum). In many fungi, septa occur at regular intervals, essentially delimiting individual cell-like compartments. In other fungi, septa are present only in special circumstances, such as to delimit a reproductive structure from an ordinary vegetative hypha. The term “septate” is used to describe fungi with regularly occurring septa, whereas those with few or no septa are referred to as coenocytic.

The hypha grows in length from the tip, and this growth can occur almost indefinitely if favorable conditions (a suitable supply of water and nutrients) persist. As it grows, the hypha spreads over or penetrates into a particular substrate, usually branching and thus expanding the mycelium of which it is part. More often than not, the mycelium occurs within the substrate and thus is not readily apparent in nature.

Growth of Fungi

The fact that some fungi appear to be capable of growing almost indefinitely under favorable conditions was borne out in an article that appeared in the April 2003 issue of the Canadian Journal of Forest Research. The authors of the article reported that a mycelium of Armillaria ostoyae (honey mushroom) apparently extended over a total area of 2200 acres (890 hectares) in the Malheur National Forest in the Strawberry Mountains of eastern Oregon (Ferguson et al. 2003). This “humongous fungus” was estimated to be more than 2000 years old and to have a total mass of as much as 605 tons (549 tonnes). If considered a single organism, this specimen would be the largest known organism in the world in terms of area and among the largest in the total amount of living biomass. Interestingly, one of the few organisms with a larger biomass is a clone of Populus tremuloides (quaking aspen) growing in the mountains of Utah that has been estimated to have a collective weight of more than 6000 tons (5443 tonnes). Since quaking aspen is an example of a tree that forms mycorrhizal associations with fungi, this clone could never have reached such a size without its fungus partner.

The most important component of the cell (or hyphal) wall of a fungus is a substance called chitin. Interestingly enough, chitin is also a major component of the exoskeleton of insects and other arthropods. However, the basic function of the fungal cell wall and the arthropod exoskeleton are quite different. The exoskeleton is a protective layer that also provides, as its name implies, an external structure to which the muscles of the organism in question are attached.

In fungi, the cell wall tends to be relatively thin, at least in most instances. While the thin cell wall does serve to maintain the form of the hypha, its main function is actually related to the manner in which fungi obtain their food. In striking contrast to the more familiar animals, which move from place to place to obtain food wherever it is available, and most plants, which produce their food through photosynthesis, most fungi (some simple motile forms represent exceptions) literally grow (generally through the elongation and proliferation of hyphae, as noted above) to reach a potential food source.

Upon reaching a food source, the fungus releases digestive enzymes (referred to as exoenzymes) into its immediate environment. These enzymes break down the large and relatively complex molecules of the food source (or substrate) into smaller molecules that can readily pass through the hyphal wall and then into the cytoplasm of the fungus. As such, digestion actually occurs on the outside of the fungus and not on the inside, as is the case for animals (including humans). Although the fungal method of obtaining food might seem less efficient than the animal method, the relative success of fungi suggests that this is not the case.

Reproduction in Fungi

Both sexual reproduction and asexual reproduction occur in fungi, although some species seem to have either lost the capability for sexual reproduction or do so only infrequently. As is true for all eukaryotic organisms, sexual reproduction involves the fusion of two nuclei and subsequent meiosis. Because this process allows for the occurrence of new combinations of genes in the offspring that are produced, it provides the basis for the changes needed to adapt to new and different environmental conditions. In short, it sets the stage for evolution. Asexual reproduction cannot do this. It simply involves the production of new individuals with the same combinations of genes. As such, the genetic “status quo” of the fungus is maintained. Although asexual reproduction might seem to offer few advantages, this is hardly the case. In fact, large numbers of asexual spores (and thus potential new individuals) can be produced in a short period of time, which greatly enhances the rapid colonization of new food sources as they become available.

Interestingly, it is now known that genetic recombination without meiosis can take place in certain fungi that only reproduce asexually. This special type of genetic recombination (referred to as parasexual reproduction) involves the fusion of two genetically different haploid nuclei to form a diploid nucleus, which then undergoes a loss of chromosomes during successive mitotic divisions until it is once again haploid but with a different complement of chromosomes than either of the original nuclei. Parasexual reproduction is thought to be comparatively rare in nature, but it does allow some degree of genetic recombination to occur in the absence of meiosis.

Although the majority of fungi appear to be capable of reproducing both sexually and asexually, the structures involved in each of the two types of reproduction are not typically produced at the same time. Moreover, a major difference often exists with respect to which is more common and/or important for a particular type of fungus. In general, asexual reproduction tends to be predominant in those fungi considered more primitive.

The reproductive structures produced by fungi are exceedingly important for another reason. With very rare exceptions, it is difficult or even impossible to identify a fungus from the features that can be observed for vegetative hyphae. Instead, our concepts of what constitutes a particular kind of fungus are based almost entirely upon the morphology of the reproductive structures. Here it should be pointed out that the application of the techniques of modern molecular biology to the study of fungi has provided a body of new data that has forced mycologists to reconsider some of these concepts, especially in terms of degrees of relatedness among different fungi.

One problem that exists, especially for many of the microscopic fungi, is that what appear to be two closely related fungi with morphologically similar (sometimes essentially identical) asexual reproductive structures produce totally different sexual reproductive structures. The reverse situation (similar sexual reproductive structures but totally different asexual reproductive structures) also occurs. Prior to the use of the molecular techniques mentioned above, this situation posed a major problem for mycologists. The availability of the body of new data from molecular-based studies has given mycologists a new perspective on relationships among these fungi.

In many fungi, the reproductive structure produced is relatively simple and often microscopic, but in others it is large and complex. These larger fruiting structures are usually referred to as fruiting bodies (or sometimes fruit bodies). The various cultivated mushrooms, grown commercially on a large scale throughout much of the world and available for sale in most local supermarkets, represent examples of such structures that are familiar to almost everyone.

Fruiting bodies vary considerably in size, shape, color, and the circumstances under which they are found. Some come in rather bizarre shapes, while others are objects of considerable beauty. Just where a fruiting body is found usually reflects the location of the mycelium from which it was produced. Accordingly, fruiting bodies that occur on wood are most likely to be associated with the mycelium of a wood-decomposing fungus, whereas those found on the ground are probably produced by fungi that either decompose dead leaves and other types of plant debris or form mycorrhizal relationships with nearby trees. Although the fruiting structures produced by microscopic fungi, a group that actually includes the vast majority of fungi, are relatively simple, many of them are quite intricate, sometimes to the point of defying the imagination.

Fungal diversity

Due to environmental destructions, which have occurred worldwide and have been a major concern to living entities. Prevention or escape from them by reduction of public pollution problems and temperature increases, and maintenance of the present conditions are essential. Thus, the biodiversities directly connected with these problems have been paid attention to, discussed, and analyzed repeatedly. Particularly, some disappearing species of higher plants and animals have routinely been news sources, but microorganisms including fungi have been neglected, although their significance has been emphasized in relation to degradation of natural resources, as well as to their movement and relocation. Biodiversity problems include qualitative and quantitative aspects and their influences to our life. Qualitatively it is essential to know as many fungal species as possible. But recent molecular techniques have suggested numerous unknown, unidentified microorganisms may be detected or isolated from nature.

In trial of repeated isolation and identification procedures, we have known certain fungal floras and listed their components including some limited species, cosmopolitan and local species or indigenous, invading or importing species and even new species, and whether alteration or variation of predominant and common species would occur seasonally and locally.

Together with the progress and development of isolation and identification techniques the knowledge of these organisms may be variously accumulated or increased. Such knowledge might have been effectively used for studies and manufacturing nutritional, fermentative, pharmaceutical, or cosmetic materials.

The fungal diversities have been studied with the following aims:

1- to clarify as many fungal taxa as possible,
2- to know fungi quantitatively,
3- to know fungi ecologically,
4- to know their biology together with the environmental factors influential to their lives,
5- to know the invading or imported taxa in the various habitats,
6- to increase public attention and opinions to access the environments readily through our knowledge and information, and to preserve voucher specimens for future and succeeding students.

The fungal diversities in nature have been understood readily through lists of the fungus flora in various habitats. However, the taxonomical and nomenclatural confusion has often rendered such lists unacceptable or useless. Thus, more accurate, reliable, and critical identification by both the traditional and modern techniques may be required, but the modern system may have been still developing, because the gene bank is still poor in accumulation of data, and the knowledge on the classical taxonomy is lacking or depending too much on it. The confusion has been partially originated from misidentification, and lack of type species, information, and communication for decades. We are now in confusion and at a loss between the traditional, morphological taxonomy and the modern, molecular taxonomy. The fungal taxonomy is now going to be divided among the two directions based on morphologies and gene analyses, partially mixing and fusing each other and developing the new concept gradually.

Morphologies of fungi have been studied as part of taxonomical criteria together with the colony characteristics mostly on agar cultures. Colony morphologies including colors and textures have been quite ambiguously described. However, the photographs of colonies are readily understood at a glance and very helpful for the introductory approaches to identify fungi. No compiled atlas on specimens has been available, although atlases are essentially and practically required by mycologists and all sorts of students in concern.

Fungal colonies may help us identify the fungi more easily together. Their compilation with the help of computers may be essential in future. Fungus colonies are commonly characterized as follows:

- Color and tint on colony surface and reverse
- Smell or fragrance of culture
- Surface structure: aerial hyphae (quantity), cottony, crustaceous, embedded, furrowed, homogeneous or heterogeneous, powdery (floury), raised, resupinate, shrunken, sloppy, sticky, thin or thick, velvety, water soaked, yeastlike
- Pattern: arachnoid, flowery, radiate, zonate
- Margin: irregular, smooth
- Growth: restricted, spreading
- Pigment exuded: color, watery
- Organs formed: fruiting structures (conidioma [pl. -ta], i.e., pycnidium [pl. pycnidia], aceluvulus [pl. acervuli], ascoma [pl. -ta], i.e., perithecium [pl. perithecia], pseudothecium [pl. pseudothecia], cleistothecia, basidioma [pl. -ta]), sporodochium (pl. sporodochia), sclerotia, setae, stroma, synnema (pl. -ata), rhizomorphs.

Fungi from Soil, Seed, and Plant Materials

In soil live numerous kinds of organisms including fungi, which keeping the individual units and populations in balance.

Fungi detected or isolated from soil are tentatively termed as soil fungi. Some of them are typical soil fungi, being isolated only from soil, and the other atypical, readily and frequently isolated from other habitats surrounding us. Fungi from the underground parts, and especially associated with soilborne diseases appear to be typical soil fungi. Some airborne fungi may be contaminated with soil and casually isolated from soil. In addition, some fungi may be isolated from animals living in soil, and may also be classified as one of the soil fungi. For example, 63 fungal species were isolated from cysts of soybean cyst nematode, *Heterodera schachili*. Some others are often isolated from seed and may be termed as seed fungi, although some of them are typical soil fungi.

Fungi detected or isolated from soil, seeds, and plant roots are soil and seed fungi without rigid definition in this text. The fungi isolated from aerial parts of plant materials and wood, and fruiting bodies on them are typical environmental fungi around us.

Soil Fungus Floras

Fungus floras in soils or associated with plant roots have been studied worldwide by compiling fungal members together with their isolation or detection frequencies initially, to understand environmental factors for soilborne disease occurrence.

Technical problems such as isolation methods, isolation techniques and media used, and incubation conditions, that is, temperatures, may influence the contents of any particular fungus floras. For example, *Mortierella* spp. and *Pythium* spp. may be detected from almost any soil by a bait method using cucumber seeds as a substrate, but they were often not listed in any old literature. We often experience that fewer fungus genera may be yielded from any plant root tissue plated on any nutrient-rich media after surface sterilization with chemicals, although more than 30 genera may be readily isolated by single hyphal tippings from the same sample just washed without sterilization on water agar by single hyphal tippings.

Many fungi remain unidentified because of nonsporulation, and they may be treated differently but significant for the work. Adoption of appropriate scientific names for these fungi is essential for the study of fungal floras.

Soil Fungi in Relation to Seed Fungi

The fungi associated with seeds are classified into two groups: field fungi contaminated with seeds in the field during harvest, and storage fungi, during transit and storage. We cannot specify when and how the contamination occurred on these seeds, but most of these fungi can live under both seed and soil conditions. There must be a few fungi limited to live in seed, which infect only seeds and complete their life cycle there. Many organisms may be introduced into soil by sowing, but some organisms penetrate, contaminate, and colonize plant tissues directly or indirectly in various growth stages, repeatedly influencing seed quality and reducing germinability. Aflatoxin and toxic substances produced by toxicogenic fungi affect the health of animals and human beings. The fungi associated with seeds have been studied from various aspects including plant pathological views, but may be studied more mycologically, because they include various interesting fungi.