Learning unit 5: Fungi

5.1 Introduction

To complete the learning unit, you will need to refer to pages 710–728 chapter 31 in Campbell et al. (2015)

The science of mycology, the study of fungi, is concerned with all these diverse life-forms. Fungi are a huge and important component of the biosphere. About 100 000 species, most of which are terrestrial, have been described, however, it is estimated that there are more than 1.5 million species. These diverse organisms are found in just about every imaginable terrestrial and aquatic habitat. Fungi grow best in moist habitats, but they are found universally wherever organic material is available. Apart from being diverse, fungi are essential for the well-being of most ecosystems. They break down organic material and recycle nutrients, allowing other organisms to assimilate essential chemical elements. When they decompose organic compounds, carbon and other elements are released into the environment, where they are recycled. Humans make use of fungi as a food source, for application in agriculture and forestry, and in manufacturing products ranging from bread to antibiotics. But it is also true that some fungi are as bad as poison as they cause disease in both plants and plants.

This learning unit investigates the structure and evolutionary history of fungi. The learning unit will also explores the major groups of fungi, and discuss their ecological and commercial significance.

5.2 Learning outcomes

By the end of this learning unit you should be able to

- explain why fungi are adapted to be decomposers and symbionts
- explain the life cycle of fungi
- describe the life cycle of the Zygomycota, clearly indicating plasmogamy, karyogamy and meiosis
- describe the life cycle of the Basidiomycota, clearly indicating plasmogamy, karyogamy and meiosis
- discuss the ecological importance of fungi

5.3 Fungi are heterotrophs that feed by absorption

Recommended reading: pages 711–713 of chapter 31 in Campbell et al. (2015)

Fungi are heterotrophs that acquire their nutrients by means absorption. They absorb small organic molecules from the surrounding medium. Fungi use exoenzymes, powerful hydrolytic enzymes, break down food outside their body into simpler compounds that the fungi can absorb and utilise further. The absorptive mode of nutrition is associated with the ecological roles of fungi as decomposers (saprobes), parasites, and mutualistic symbionts. **Saprobic fungi** absorb nutrients from non-living organisms. **Parasitic fungi** absorb nutrients from the cells of living hosts. Some parasitic fungi, including some that infect humans and plants, are pathogenic. It has been reported that fungi cause about 80% of plant diseases. **Mutualistic fungi** also absorb nutrients from a host organism, but they reciprocate with functions that surely benefit their partner in some way.

Body structure adapts fungi for absorptive nutrition

Yeasts are single-celled fungi. Most species of fungi are multicellular. The vegetative bodies of most fungi are constructed of tiny filaments called **hyphae** that form an interwoven mat called a mycelium. Fungal hyphae have cell walls. These are built mainly of **chitin**, a strong but flexible nitrogen-containing polysaccharide identical to that found in arthropods. Most fungi are multicellular with hyphae divided into cells by cross walls, or **septa**. These generally have pores large enough for ribosomes, mitochondria, and even nuclei to flow from cell to cell. Fungi that lack septa, coenocytic fungi, consist of a continuous cytoplasmic mass with hundreds or thousands of nuclei. This results from repeated nuclear division without cytoplasmic division. Parasitic fungi usually have some hyphae modified as **haustoria**, nutrient-absorbing hyphal tips that penetrate the tissues of their host. Some fungi even have hyphae adapted for preying on animals. The filamentous structure of the mycelium provides an extensive surface area that suits the absorptive nutrition of fungi. One cubic centimetre of rich organic soil may contain 1 km of fungal hyphae with a surface area of more than 300 cm^2. A fungal mycelium grows rapidly. Proteins and other materials synthesised by the entire mycelium are channelled by cytoplasmic streaming to the tips of the extending hyphae. The fungus concentrates its energy and resources on adding hyphal length and absorptive surface area. While fungal mycelia are non-motile, by swiftly extending the tips of its hyphae it can extend into new territory.

5.3.1 Activity 5.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

b. Describe the distinguishing characteristics of fungi on feeding mode.
d. Describe the body plan of a fungus.
f. Compare and contrast the nutritional mode of a fungus with your own nutritional mode.

5.3.2 Feedback on activity 5.1

In answering a) Fungi are eukaryotic heterotrophs that secrete digestive enzymes onto their food source and then absorb the predigested food. b) Make sure that in your answer you have included hyphae, mycelium, and septa or cross walls. c) Both a fungus and a human are heterotrophs. Many fungi digest their food externally by secreting enzymes into the food and then absorb the small molecules that result from digestion. Other fungi absorb such small molecules directly from their environment. In contrast, humans (and most other animals) ingest relatively large pieces of food and digest the food within their bodies.

5.4 Fungi produce spores through sexual or asexual life cycles

Recommended reading: pages 713–715 of chapter 31 in Campbell et al. (2015)

Fungi reproduce by producing vast numbers of spores, either sexually or asexually. The output of spores from one reproductive structure can be enormous, since puffballs may release trillions of spores. Dispersal is widely driven by wind or water. Spores germinate to produce mycelia if they land in a moist place where there is food.

Many fungi have a heterokaryotic stage

The nuclei of fungal hyphae and spores of most species are haploid, except for transient diploid stages that form during sexual life cycles. Sexual reproduction in fungi begins when hyphae from two genetically distinct mycelia release sexual signaling molecules called pheromones. Pheromones from each partner bind to receptors on the surface of the other. The union of the cytoplasm of the two parent mycelia is known as **plasmogamy** (See Figure 31.5 from your prescribed textbook). In some species, **heterokaryotic** mycelia become mosaics, with different nuclei remaining in separate parts of the same mycelium or mingling and even exchanging chromosomes and genes. In some fungi, the haploid nuclei pair off two to a cell, one from each parent. Such a mycelium is known as **dikaryotic**, meaning “two nuclei.” In many fungi with sexual life cycles, **karyogamy**, fusion of haploid nuclei contributed by two parents, occurs well after plasmogamy, cytoplasmic fusion of cells from the two parents. The delay may be hours, days, months or even centuries. During karyogamy, the haploid nuclei contributed by the two parents fuse, producing diploid cells. Whereas, in most fungi the zygotes of transient structures formed by karyogamy are the only diploid stages in the life cycle. These undergo meiosis to produce haploid cells that develop as spores in specialized reproductive structures. These spores disperse to form new haploid mycelia. The sexual processes of karyogamy and meiosis generate genetic variation. The heterokaryotic condition also offers some of the advantages of diploid, in that one haploid genome may be able to compensate for harmful mutations in the other.

Many fungi reproduce asexually

The processes of asexual reproduction in fungi vary widely. Some species reproduce only asexually. Some fungi that can reproduce asexually grow as mold. Molds grow rapidly as mycelia and produce spores. Yeasts live in liquid or moist habitats. Instead of producing spores, yeasts reproduce asexually by simple cell division or by budding of small cells. Most molds and yeasts have no known sexual stage. Such fungi are called **deuteromycetes**, or imperfect fungi. Whenever a sexual stage of a deuteromycete is discovered, the species is classified in a particular phylum depending on its sexual structures. Fungi can be identified from their sexual stages and by new genetic techniques.

5.5 The ancestor of fungi was an aquatic, flagellated protist

Recommended reading: pages 715–716 of chapter 31 in Campbell et al. (2015)

Data from paleontology and molecular systematics offer insights into the early evolution of fungi. Systematists recognize Fungi and Animalia as sister kingdoms. Interesting to know, fungi and animals are more closely related to each other than they are to plants or other eukaryotes.

Phylogenetic systematics suggests that fungi evolved from a unicellular, flagellated protist. The lineages of fungi that diverged earliest (the **chytrids**) have flagella. Members of the clade Opisthokonta, including animals, fungi, and closely related protists, possess flagella. This name refers to the posterior (opistho) location of the flagellum. Scientists estimate that the ancestors of animals and fungi diverged into separate lineages 1.5 billion years ago. However, the oldest undisputed fungal structures are only 460 million years old. It is likely that the first fungi were unicellular and did not fossilise. Fungi underwent an adaptive radiation when life began to colonise land. Fossils of the first vascular plants from the Silurian period contain evidence of mycorrhizae, symbiotic relationships between plants and subterranean fungi.

5.6 Fungi have radiated into a diverse set of lineages

Recommended reading: pages 716–723 of chapter 31 in Campbell et al. (2015)

Fungi classified in the phylum Chytridiomycota, called the chytrids, are widespread in lakes, ponds, and soil. As mentioned before, some are saprobes, while others parasitise protists, plants, and animals. However, recent molecular evidence supports the hypothesis that chytrids diverged earliest in fungal evolution. Like other fungi, chytrids use an absorptive mode of nutrition, have chitinous cell walls, and have similar key enzymes and metabolic pathways. While there are a few unicellular chytrids, most form coenocytic hyphae. Chytrids are unique among fungi in having flagellated spores, called **zoospores**. Until recently, systematists thought that fungi lost flagella only once in their history, after chytrids had diverged from other lineages. However, molecular data now indicates that some flagellated fungi are more closely related to another fungal group, the zygomycetes. If this is true, flagella were lost on more than one occasion during fungal evolution.

Phylum Zygomycota: Zygote fungi form resistant structures during sexual reproduction

The 1 000 zygomycetes exhibit a considerable diversity of life history. The phylum includes fast-growing molds, parasites, and commensal symbionts. The life cycle and biology of *Rhizopus stolonifer*, black bread mold, is typical of zygomycetes. The hyphae are coenocytic, with septa found only where reproductive cells are formed. Horizontal hyphae spread out over food, penetrate it, and digest nutrients. In the asexual phase, hundreds of haploid spores develop in sporangia at the tips of upright hyphae. Some zygomycetes, such as *Pilobolus*, can actually aim their sporangia toward conditions that would be favourable for their spores. If environmental conditions deteriorate, *Rhizopus* may reproduce sexually. Plasmogamy of opposite mating types produces a zygosporangium. Inside this multinucleate structure, the heterokaryotic nuclei fuse to form diploid nuclei that undergo meiosis. The zygosporangia are resistant to freezing and drying. When conditions improve, the zygosporangia undergo meiosis and release haploid spores that colonise new substrates.

Microsporidia are unicellular parasites

Microsporidia are unicellular parasites of animals and protists. They are often used in biological control of insect pests. Microsporidia lack conventional mitochondria, and represent something of a taxonomic mystery. Some researchers suggest that they are an ancient, deep-branching eukaryotic lineage. Recent evidence suggests that they are highly derived parasites that may be related to zygomycete fungi.

Glomeromycetes form mycorrhizae

Only 160 species of glomeromycetes have been identified. Nonetheless, they are an economically significant group. All glomeromycetes form symbiotic mycorrhizae with plant roots. Mycorrhizal fungi can deliver phosphate ions and other minerals to plants. In exchange, the plants supply the fungi with organic nutrients. There are several different types of mycorrhizal fungi. Ectomycorrhizal fungi form sheaths of hyphae over the surface of the plant root and grow into the extracellular spaces of the root cortex. Endomycorrhizal fungi extend their hyphae through the root cell wall and into tubes formed by invagination of the root cell membrane. Glomeromycetes all form a distinct type of endomycorrhizae called arbuscular mycorrhizae. The tips of the hyphae that push into plant root cells branch into tiny treelike structures known as **arbuscles**. Such symbiotic partnerships with glomeromycetes are present in 90% of all plants.

Phylum Ascomycota: Sac fungi produce sexual spores in saclike asci

Mycologists have described more than 32 000 species of ascomycetes, or sac fungi, from a variety of marine, freshwater, and terrestrial habitats. Ascomycetes produce sexual spores in saclike asci and are called sac fungi. Most ascomycetes bear their sexual stages in fruiting bodies called ascocarps. They range in size and complexity from unicellular yeasts to elaborate cup fungi and morels. Some are devastating plant pathogens. Many are important saprobes, particularly of plant material. About 40% of ascomycete species live with green algae or cyanobacteria in mutualistic associations called **lichens**. Some ascomycetes form mycorrhizae with plants or live between mesophyll cells in leaves where they may help protect the plant tissue from insects by releasing toxins. Ascomycetes reproduce asexually by producing enormous numbers of asexual spores, which are usually dispersed by the wind. These naked spores, or conidia, develop in long chains or clusters at the tips of specialized hyphae called conidiophores. Ascomycetes are characterized by an extensive heterokaryotic stage during the formation of ascocarps. Plasmogamy between two parental hyphae produces a heterokaryotic bulge called an ascogonium. The coenocytic ascogonium extends hyphae that are partitioned by septa into dikaryotic cells, each with two haploid nuclei representing two parents. The cells at the tip of these dikaryotic hyphae develop into asci. Within an ascus, karyogamy combines the two parental genomes, and meiosis forms four genetically different nuclei forming eight ascospores. In many asci, the eight ascospores are lined up in a row in the order in which they formed from a single zygote nucleus. One of the best-studied ascomycetes is Neurospora crassa, a bread mold. This ascomycete serves as a model organism.

Phylum Basidiomycota: Club fungi have long-lived dikaryotic mycelia

Approximately 30 000 fungi, including mushrooms and shelf fungi, are called basidiomycetes and are classified in the phylum Basidiomycota. The name of the phylum is derived from the basidium, a transient diploid stage. The club-like shape of the basidium is responsible for the common name club fungus. Basidiomycetes are important decomposers of wood and other plant materials. Of all fungi, the saprobic basidiomycetes are best at decomposing the complex polymer lignin, abundant in wood. The life cycle of a club fungus usually includes a long-lived dikaryotic mycelium. Environmental cues, such as rain or temperature change, induce the dikaryotic mycelium to reproduce sexually by producing elaborate fruiting bodies called basidiocarps. A mushroom is a familiar basidiocarp that can pop overnight as it absorbs water and as cytoplasm steams in from the dikaryotic mycelium. The dikaryotic mycelia are long-lived, generally producing a new crop of basidiocarps each year. The cap of a mushroom supports and protects a large surface area of basidia on the gills. The basidia form sexual spores called basidiospores. A common white mushroom has a gill surface of about 200 cm^2 and may release a billion basidiospores, which drop from the cap and blow away. Asexual reproduction is much less common in basidiomycetes than in ascomycetes. Watch the following video which shows the sexual and asexual reproduction of fungi: https://www.youtube.com/watch?v=uMucnzlH4qk

5.7 Fungi play key roles towards the environment as well as human welfare

Recommended reading: pages 723–727 of chapter 31 in Campbell et al. (2015)

Ecosystems depend on fungi as decomposers and symbionts

Fungi are important decomposers of organic material, including cellulose and lignin of plant cell walls. Fungi and bacteria are essential for providing ecosystems with the inorganic nutrients responsible for plant growth. Without decomposers, carbon, nitrogen, and other elements would become tied up in organic matter. Fungi form symbiotic relationships with plants, algae, and animals. Mycorrhizae are extremely important in natural ecosystems and agriculture. Almost all vascular plants have mycorrhizae and rely on their fungal partners for essential nutrients. Some fungi break down plant material in the guts of cows and other grazers. Many species of ants and termites raise fungi in “farms.” The fungi break the leaves down into a substance that the insects can digest. Some mutualistic associations between “farmer” insects and “farmed” fungi have been established for more than 50 million years. In many cases, the fungi can no longer survive without the insects. Lichens are a symbiotic association of millions of photosynthetic microorganisms held in a mesh of fungal hyphae. The fungal component is commonly an ascomycete, but several basidiomycete lichens are known. The photosynthetic partners are usually unicellular or filamentous green algae or cyanobacteria. The fungal hyphae provide most of the lichen’s mass and give it an overall shape and structure. The algae or cyanobacteria usually occupy an inner layer below the lichen surface. The merger of fungus and algae is so complete that they are actually given genus and species names, as though they were single organisms. More than 13 500 species of lichen have been described—a fifth of all known fungi. In most lichens, each partner provides things that the other could not obtain on its own. For example, the alga provides the fungus with food by “leaking” carbohydrate from their cells. The cyanobacteria provide organic nitrogen through nitrogen fixation. The fungus provides a suitable physical environment for growth, retaining water and minerals, allowing for gas exchange, shading the algae or cyanobacteria from intense sunlight with pigments, and deterring consumers with toxic compounds. The fungus also secretes acids, which aids in the uptake of minerals. The fungi of many lichens reproduce sexually by forming ascocarps or basidiocarps. Lichen algae reproduce independently by asexual cell division. Asexual reproduction of symbiotic units occurs either by fragmentation of the parental lichen or by the formation of structures called **soredia**, small clusters of hyphae with embedded algae. Phylogenetic studies of lichen DNA have helped illuminate the evolution of this symbiosis. The same studies also suggest that many free-living fungi, including *Penicillium*, descended from lichen-forming ancestors. Lichens are important pioneers on newly cleared rock and soil surfaces, such as burned forests and volcanic flows. The lichen acids penetrate the outer crystals of rocks and help break down the rock. This allows soil-trapping lichens to establish and starts the process of succession. Nitrogen-fixing lichens also add organic nitrogen to some ecosystems. Some lichens can survive severe cold or desiccation. In the arctic tundra, herds of caribou and reindeer graze on carpets of reindeer lichens under the snow in winter. In dry habitats, lichens may absorb water quickly from fog or rain, gaining more than ten times their mass in water. Lichens are particularly sensitive to air pollution, and their deaths can serve as an early warning of deteriorating air quality.

Some fungi are pathogens

About 30% of the 100 000 known species of fungi are parasites, mostly on or in plants. Invasive ascomycetes have had drastic effects on forest trees such as American elms and American chestnuts in the northeastern United States. Other fungi, such as rusts and ergots, infect grain crops, causing tremendous economic losses each year. Fungi are also serious agricultural pests. Between 10% and 50% of the world’s fruit harvest is lost each year to fungal attack. Some fungi that attack food crops produce compounds that are harmful to humans. For example, the mold *Aspergillus* can contaminate improperly stored grains and peanuts with aflatoxins, which are carcinogenic. Poisons produced by ergots of the ascomycete *Claviceps purpurea* can cause gangrene, nervous spasms, burning sensations, hallucinations, and temporary insanity when infected rye is milled into flour and consumed. One of the compounds to have been isolated from ergots is lysergic acid, the raw material from which the hallucinogen LSD is made. Animals are much less susceptible to parasitic fungi than are plants. Only about 50 fungal species are known to parasitise humans and other animals, but their damage can be disproportionate to their taxonomic diversity. The general term for a fungal infection is mycosis. Infections of ascomycetes produce the disease ringworm, known as athlete’s foot when they grow on the feet. Systemic mycoses spread through the body and cause very serious illnesses. They are typically caused by inhaled spores. Coccidiodomycosis is a systemic mycosis that produces tuberculosis-like symptoms in the lungs. It is so deadly that it is now considered a potential biological weapon. Some mycoses are opportunistic, occurring only when a change in the body’s microbiology, chemistry, or immunology allows the fungi to grow unchecked. *Candida albicans* is a normal inhabitant of moist epithelia such as human vaginal lining, but it can become an opportunistic pathogen. Other opportunistic mycoses have become more common due to AIDS, which weakens the immune system.

Fungi are commercially important

In addition to the benefits that we receive from fungi in their roles as decomposers and recyclers of organic matter, we use fungi in a number of ways. Most people have eaten mushrooms, the fruiting bodies (basidiocarps) of subterranean fungi. The fruiting bodies of certain mycorrhizal ascomycetes, truffles, are prized by gourmets for their complex flavors. The distinctive flavors of certain cheeses come from the fungi used to ripen them. The ascomycete mold *Aspergillus* is used to produce citric acid for colas. Yeasts are even more important in food production. Yeasts are used in baking, brewing, and winemaking. The yeast *Saccharomyces cerevisiae* is the most important of all cultured fungi, and is available in many strains as baker's and brewer's yeast. Contributing to medicine, some fungi produce antibiotics used to treat bacterial diseases. In fact, the first antibiotic discovered was penicillin, made by the common mold *Penicillium*. A compound extracted from ergots is used to reduce high blood pressure and stop maternal bleeding after childbirth. Fungi play an important role in molecular biology and biotechnology. Researchers use *Saccharomyces* to study the molecular genetics of eukaryotes. Scientists have learned about the genes involved in Parkinson's and Huntington's diseases by examining the homologous genes in *Saccharomyces*. Genetically modified fungi are used to produce human glycoproteins.

5.8 Activity 5.2

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

b. What types of reproduction occur in fungi?
d. What are mycorrhizas? How do both fungi and plants benefit from this ecological interaction?
f. What are lichens? How do fungi participate in this ecological interaction?
h. Discuss the economic importance of yeast which belongs to kingdom Fungi.

5.9 Feedback on activity 5.2

In answering a) In fungi, both asexual and sexual reproduction occur. Fungi reproduce asexually by fragmentation, gemmation and sporulation. Some species can reproduce sexually through the fusion of hyphae from different specimens, and even with metagenesis (alternation of generations).

b) Mycorrhizas are mutualistic ecological interactions between fungi and some plant roots. Fungi provide more water and mineral salts to the plant and obtain organic material from the plant in return.

c) Lichens are formed through the mutualist ecological interaction between fungi and algae or between fungi and cyanobacteria. In this ecological interaction, the fungi absorb water that is then used by algae (or cyanobacteria), and the algae (or cyanobacteria), as autotrophs, produce organic material in excess to serve as food for the fungi.

Remember that your approach to this question (d) may differ slightly from mine; however, this is how you can attempt question d) They play an important role in brewing and baking industry. They form alcoholic beverages under anaerobic conditions. *Saccharomyces cerevisiae* plays an important role in brewing industry. This species also play an important role in baking industry by forming carbon dioxide and alcohol. They are also used as vitamin rich food. They also spoil food stuffs. They play a vital role in formation of silk. Some of the species like *Candida albicans* attack human beings and lead to thrush and inflammation of genital organs. Some of the species of *Cryptococcus* and *Torula* also attack human beings.

5.10 Summary

All fungi (include decomposers and symbionts) are heterotrophs that acquire nutrients by absorption. Many fungi secrete enzymes that break down complex molecules. Most fungi grow as thin, multicellular filaments called hyphae, whereas, relatively few species grow only as single-celled yeasts.

In fungi, the sexual life cycle involves cytoplasmic fusion (plasmogamy) and nuclear fusion (karyogamy), with an intervening heterokaryotic stage in which cells have haploid nuclei from two parents. The diploid cells resulting from karyogamy are short-lived and undergo meiosis, producing genetically diverse haploid spores. Many fungi can reproduce asexually as filamentous fungi or yeasts.

Chytrids is a group of fungi with flagellated spores, including some basal lineages. Fungi were recorded among the earliest colonisers of land. Moreover, fossil evidence indicates that these included species that were symbionts with early land plants. There are five existing fungal phyla namely; Chytridiomycota, Zygomycota, Glomeromycota, Ascomycota, and lastly, Basidiomycota.

Fungi perform essential recycling of chemical elements between the living and non-living world. Lichens are highly integrated symbiotic associations of fungi and algae or cyanobacteria. Many fungi are parasites, mostly of plants. Humans use fungi for food and to make antibiotics.