CHAPTER 36: FUNGI

CHAPTER SYNOPSIS

Even though fungi have been traditionally classified with plants, the two kingdoms have little in common. Plants are photosynthetic, while fungi obtain nutrients by secreting enzymes into their substrate and absorbing the digested materials. Plants are composed of several types of cells organized into tissues and organs, while fungi are basically filamentous, even though those filaments may be packed into complex structures like mushrooms. Plant cell walls contain cellulose, fungi cell walls are impregnated with chitin. Some plants have flagellated sperm, fungi sperm are all nonflagellated. Plants and fungi are similar only in their immobility and their linear reproductive structures. Fungi are also different from either plants or animals in their cell division. The nuclear envelope remains intact during mitosis, the spindle apparatus forms within the nucleus and is regulated by spindle plaques. Fungi are similar to bacteria in their ecological and commercial value. They are among the few organisms that are able to decompose lignin, a major constituent of wood.

Fungi are composed of filamentous hyphae; a mass of hyphae is called the mycelium. In one phylum the hyphae are nonseptate, there is no separation into individual cells except where reproductive cells form. In the other two phyla the hyphae are septate, but the barrier between vegetative cells is incomplete and cytoplasm flows freely from one cell to the next. The septae are complete only where reproductive cells are formed. All fungal nuclei are haploid, except those of the zygote. Homokaryotic hyphae contain genetically similar nuclei while heterokaryotic hyphae contain two kinds of genetically different nuclei. In monokaryotic hyphae each compartment possesses only one haploid nucleus while dikaryotic hyphae possess two genetically distinct haploid nuclei per compartment. Fungi produce three types of reproductive structures: Sporangia, gametangia, and/or conidiophores. Fungi and bacteria are the earth's principal decomposers. They are used in the industrial production of many chemical compounds and are capable of detoxifying the environment. Fungi are important in the manufacture of bread and alcohol and help flavor wine, cheese, and other foods.

Fungi are classified into phyla according to their sexual reproductive structures. In the Zygomycetes, hyphae fuse and produce a hard-walled zygote that undergoes meiosis at germination. In both the Ascomycota and the Basidiomycota, reproductive cells are produced from dikaryotic hyphae with meiosis immediately following syngamy. Ascomycetes produce eight haploid spores within a sac-like ascus, basidiomycetes produce four haploid spores on the tip of a club-shaped basidium. Asexual reproduction occurs in the Zygomycota and Ascomycota, but is rare in the Basidiomycota. Zygomycete molds produce asexual spores within sporangia, ascomycete molds produce chains of asexual spores on conidiophores. Morels, cup fungi, and truffles are also in the phylum Ascomycota, as are most yeasts. Basidiomycetes include common mushrooms, bracket fungi, puffballs, rusts, and smuts. The Imperfect Fungi include individuals in which sexual reproduction has not been observed. They resemble other fungi in structure and asexual reproduction, but are not formally classified until sexual reproduction is fully characterized. Imperfect fungi may exhibit parasexuality, a form of genetic recombination where parts of chromosomes from genetically different nuclei are exchanged.

Fungi form important symbiotic associations with plants in lichens and mycorrhizae. A lichen is a symbiotic association between a fungus and a photosynthesizer. They generally inhabit cold, dry inhospitable environments and help prepare the habitat for other organisms. They are extremely sensitive to pollution. Endomycorrhizae are fungal hyphae that penetrate the outer cells of plant roots. There are over 100 species, generally zygomycetes, associated with over 200,000 kinds of plants. They likely increase crop yields with less input of energy, provide better growth in poor soils, and may have added plants in their initial invasion of the land. Ectomycorrhizae are symbionts of temperate tree and shrub roots. Most are basidiomycetes, some are ascomycetes.

CHAPTER OBJECTIVES

- Understand why fungi are not classified with plants and how they are fundamentally different from other living organisms.
- Understand the reproductive uniqueness of the fungi.
- Compare and contrast the three phyla of fungi.
- Describe a typical life cycle of a zygomycete, including sexual and asexual reproductive phases.
- Understand the sexual reproductive cycle of the Ascomycetes, know which hyphae are monokaryotic and which are dikaryotic.
- Know how yeasts differ from other fungi.
- Delineate the reproductive and structural similarities between Ascomycota and Basidiomycota.
- Understand the sexual reproductive cycle of the Basidiomycetes, know which hyphae are homokaryotic and which are dikaryotic and heterokaryotic.
- Understand the significance of the Imperfect Fungi especially as it concerns parasexuality.
- Know what important symbiotic relationships exist between fungi and photosynthetic organisms.
- Differentiate between endomycorrhizae and ectomycorrhizae.

KEY TERMS

antheridium
ascocarp
ascogonium
ascomycetes
ascospore
ascus (asci)
basidiocarp
basidiomycetes
basidiospore
basidium (basidia)
conidium (conidia)
conidiophore
dikaryotic
ectomycorrhiza
endomycorrhiza
external digestion
gametangium (gametangia)
heterokaryotic
homokaryotic
hypha (hyphae)
lichen
monokaryotic
mycelium (mycelia)
mycologist
mycorrhiza
parasexuality
primary mycelium
secondary mycelium
septum (septa)
spindle plaque
sporangiophore
sporangium (sporangia)
sterigma (sterigmata)
trichogyne
yeast
zygomycetes
zygosporangium (zygosporangia)

CHAPTER OUTLINE

36.0 Introduction

I. UNIQUE CHARACTER OF FUNGI fig 36.1

A. Multicellular Organisms Capable of Rapid Growth

B. Share Very Few Characteristics with Plants
1. Are multicellular
2. Most grow in ground

36.1 Fungi are unlike any other kind of organism

I. A FUNGUS IS NOT A PLANT

A. Fungi Are Members of a Distinct Kingdom of Organisms fig 36.2
1. Studied by mycologists
2. Traditionally classified as plants
   a. Unlike plants due to lack of chlorophyll
   b. Like plants in general appearance and immobility

B. Differences Between Fungi and Plants
1. Fungi are heterotrophs
   a. Mushrooms are not green, do not photosynthesize like plants
   b. Fungi absorb food after secretion of enzymes and extracellular digestion
   c. Absorb resulting organic molecules
2. Fungi have filamentous bodies
   a. Fungi are composed of long, slender filaments
   b. Filaments may be packed into complex structures like mushrooms
   c. Plants are composed of several types of cells organized into tissues and organs
3. Fungi have unusual reproductive modes
   a. Some plants have flagellated sperm while fungi do not
   b. Most fungi reproduce sexually with nuclear exchange
4. Fungi have cell walls made of chitin
   a. Fungi cell walls made of polysaccharides and chitin
   b. Plant cell walls are made of cellulose
5. Fungi have nuclear mitosis
   a. Very different from plants or other eukaryotes
   b. Nuclear envelope does not break down and reform
   c. Mitosis occurs within the nucleus
   d. Spindle apparatus forms inside nucleus, chromosomes are dragged to poles of nucleus
6. DNA studies confirm vast differences from other organisms

II. THE BODY OF A FUNGUS

A. Filamentous Growth Form
1. Slender filaments called hyphae (hypha, singl.)
2. May be divided into cells by septa (septum, singl.)
   a. Barrier incomplete except when separating reproductive cells
   b. Cytoplasm flows freely through pores in septa fig 36.3
   c. Results in rapid growth with optimum food, water, and temperature
3. Mass of hyphae called mycelium (mycelia, pl.) fig 36.4
   a. If strung end-to-end would be many meters long
   b. Grows through and penetrates substrate
   c. All parts are metabolically active and interact with environment
   d. Rapid growth conspicuous if visible reproductive structures formed

B. Unique Cellular Composition
1. Cell wall
   a. Polysaccharide plus chitin (not cellulose like plants)
   b. Same component of arthropod exoskeleton
   c. Supports idea of common ancestor for animals and fungi
2. Distinctive form of mitosis
   a. Nuclear envelope remains intact
   b. Spindle apparatus forms within nuclear envelope

c. Lack centrioles
d. Microtubule formation regulated by spindle plaques
3. Origin from some unknown single-celled eukaryote with similar characteristics

III. HOW FUNGI REPRODUCE

A. Fungal Genetic Status

1. All nuclei haploid except for zygote nuclei, many nuclei in common cytoplasm
2. Hyphae of two different mating strains meet and fuse
3. Similar sexual reproduction in two of the three phyla
   a. After fusion of hyphae, nuclei do not immediately combine
   b. Two types of nuclei coexist without fusion for most of the life of the fungus
4. Important terminology
   a. Heterokaryotic hyphae derived from forms with two genetically different nuclei
   b. Homokaryotic hyphae have genetically similar nuclei
   c. Dikaryotic if hyphal compartment has two genetically distinct nuclei
   d. Monokaryotic if compartment has a single nucleus
5. Dikaryotic hyphae have some properties of diploids, both genomes transcribed

B. Types of Reproductive Structures

1. Cytoplasm flows freely if no septa, or through perforations in septa
2. Reproductive structures are separated with complete septa, without perforations
3. Three kinds of reproductive structures
   a. Sporangia: Involved in spore formation
   b. Gametangia: Structures in which gametes are formed
   c. Conidiophores: Produce multinucleate asexual spores called conidia
4. Spores are always non-motile
   a. Produced by asexual or sexual processes
   b. Germinate upon landing on suitable substrate
   c. Distribution via wind, over great distances
   d. Dispersed by insects, small animals

IV. HOW FUNGI OBTAIN NUTRIENTS

A. Fungi Exhibit External Digestion

1. Secrete digestive enzymes into environment
2. Extensive hyphal network provides great surface for absorption
3. Many can break down cellulose
   a. Cleave link between glucose units, absorb glucose as food
   b. Fungi often grow on dead trees

B. Some Fungi Are Predators fig 36.5

1. Mycelium of *Pleurotus ostreatus* attacks nematodes
   a. Secretes substance that anesthetizes roundworm that feeds on fungus
   b. Hyphae envelop and penetrate bodies, absorb nutrients
   c. Bulk of mushroom's glucose absorbed from digestion of wood fibers
   d. Nematodes serve primarily as nitrogen source
2. Other fungi are more active predators
   a. Snare, trap, or fire projectiles
   b. Attack nematodes, rotifers, small animals

V. ECOLOGY OF FUNGI

A. Fungi and Bacteria Are the Principal Decomposers in Biosphere
1. Breakdown organic molecules, return substances to ecosystem
2. Break down lignin, a major part of wood
3. Provide critical building blocks for growth of other organisms
4. Some fungi attack still living organic matter
   a. Cause diseases in plants and animals, cause agricultural damage fig 36.6
   b. Destroy food stores making them unpalatable or poisonous

B. Economic Value of Fungi
1. Yeasts are used in the manufacture of bread and beer
   a. Produce ethanol and carbon dioxide
   b. Used to flavor cheese, wine, and other foods
2. Fungi used in industrial production of acids, antibiotics, and chemical syntheses
3. Convert one complex organic compound to another
   a. Detoxify environment
   b. Three species isolated that combine selenium with harmless volatile chemicals

C. Important Mutualistic Associations
1. Lichens = fungi + green algae or cyanobacteria
2. Mycorrhizae = fungi + plant roots
3. Partners perform specific duties
   a. Photosynthetic organism fixes carbon dioxide and provides organic materials
   b. Fungal portion enhances existence within a particular habitat
4. Mycorrhizae facilitate absorption of essential nutrients by plant roots

36.2 Fungi are classified by their reproductive structures

I. THREE PHYLA OF FUNGI

A. Historical Aspects of Classification
1. Four groups tbl 36.1, fig 36.7
   a. Phylum Zygomycota: The zygomycetes
   b. Phylum Ascomycota: The ascomycetes
   c. Phylum Basidiomycota: The basidiomycetes
   d. Imperfect fungi
2. Presently differentiated from protist slime molds and water molds (both are protists)
   a. Characteristics of oomycetes (water molds)
      1) Motile spores
      2) Cellulose-rich cell walls
      3) Regular patterns of mitosis
      4) Diploid hyphae
3. Differentiation of phyla by sexual reproductive structures
   a. Zygomycetes
      1) Hyphal fusion results in formation of zygote
      2) Zygote undergoes meiosis at germination
   b. Ascomycetes and basidiomycetes
      1) Distinctive reproductive cells formed from dikaryotic hyphae
      2) Nuclear fusion immediately followed by meiosis
   c. Imperfect fungi lack identified asexual or sexual structures

II. PHYLUM ZYGOMYCOTA

A. Growth Form
1. Nonreproductive hyphae lack septa
2. Include common bread molds fig 36.8
3. Produce characteristic zygospores, temporarily dormant structures

B. Typical Life Cycle fig 36.8b
1. Sexual reproduction via fusion of multinucleate gametangia
   a. Gametangium cut off from hypha by complete septum
   b. May occur between same or different mating types
2. Presence of + and – strains in a colony
   a. Nuclei of different mating types may fuse
   b. Form diploid zygote nuclei
   c. Massive haploid zygosporangium forms around diploid zygote nuclei
   d. Zygosporangium may contain one or more diploid nuclei
   e. Meiosis occurs during germination of zygosporangium
   f. Haploid hyphae grow from haploid cells produced during meiosis
   g. All nuclei are haploid except for zygote nuclei
3. Asexual reproduction is common
   a. Hyphae grow over surface of material like bread
   b. Erect hyphae form sporangiophores
   c. Sporangium forms at tip, have separating septum
   d. Haploid spores produced within sporangia
   e. Spores shed above substrate, dispersed by wind

III. PHYLUM ASCOMYCOTA

A. Economically Important Fungi
1. Beneficial forms include yeast, molds, morels, and truffles fig 36.9
2. Harmful forms include chestnut blight and Dutch elm disease

B. Typical Life Cycle
1. Characteristic reproductive structure called ascus (asci, pl.)
   a. Diploid zygote formed within haploid ascus fig 36.9b
   b. Asci form on ascocarp of densely interwoven hyphae
2. Asexual reproduction is common
   a. Conidia (conidium, singl.) are produced at ends of conidiophores
   b. Spores separated from hyphae by septa
   c. Conidia may be multinucleate
   d. Hyphae are septate, but septae are perforated and cytoplasm flows through them
   e. Septae at reproductive structures are initially perforated but are sealed later
3. Multinucleate hyphae may be homokaryotic or heterokaryotic
4. Multinucleate gametangia are specialized hyphae
   a. Ascogonia are female gametangia, have trichogyne outgrowth
   b. Antheridia are male gametangia that fuse with trichogyne
   c. Male nuclei travel to ascogonium through trichogyne to pair with opposite nuclei
   d. Heterokaryotic, dikaryotic hyphae arise from area of fusion
   e. An ascus containing two nuclei forms at hyphal tip, separated by septa
   f. Nuclei fuse forming diploid zygote, immediately undergoes meiosis
   g. Four haploid daughter nuclei formed
   h. Daughter nuclei divide by mitosis forming eight ascospores
5. Ascocarps may burst to release ascospores

C. Yeasts
1. Unicellular, mostly ascomycetes
2. Most reproduction is asexual cell fission or budding fig 36.10
3. Fusion of two cells produces one cell with two nuclei
   a. Functions as an ascus, undergoes sexual reproduction
   b. Syngamy followed immediately by meiosis
   c. Ascospores function as new yeast cells
4. Diverse degenerate fungi derived from filamentous forms
   a. Yeasts related only by being single-celled
   b. Most are ascomycetes, but other two groups are represented
   c. Even ascomycetes are not clearly related to one another
5. Putting yeasts to work
   a. Ferment carbohydrates, produce carbon dioxide and ethanol
      1) Different strains selected, domesticated for specific purposes
      2) Important yeast is *Saccharomyces cerevisiae*
   b. Many are also pathogens, including *Candida*
   c. Important future in genetic engineering
      1) Model system for eukaryotic genetics
      2) Synthesized a functional artificial chromosome in 1983
      3) Whole genome sequenced in 1996

IV. PHYLUM BASIDIOMYCOTA

A. Typical Fruiting Body Form
1. Include mushrooms, jelly fungi, puffballs, rusts, and smuts fig 36.11
2. Include edible and poisonous varieties

B. Typical Life Cycle
1. Characteristic, club-shaped reproductive structure called a basidium (basidia, pl.)
   a. Karyogamy occurs within basidium; forms diploid zygote fig 36.11b
   b. Meiosis occurs immediately, forming four haploid basidiospores
   c. Four basidiospores borne on one sterigma (sterigmata, pl.)
   d. Spore germinates forming homokaryotic hyphae
   e. Hyphae initially lack septae
2. Eventually, septa form between nuclei of monokaryotic primary mycelium
3. Secondary mycelium forms when hyphae of different mating types fuse
   a. Secondary mycelium is dikaryotic and heterokaryotic
   b. Two different mating type nuclei present between a pair of septa
   c. Two genomes allow for greater genetic plasticity
   d. One genome may compensate for mutations in the other
4. Basidiocarps form of completely dikaryotic mycelium
5. Basidia line gills of typical mushrooms

V. THE IMPERFECT FUNGI

A. Also Called Deuteromycetes
1. Sexual reproductive stages not observed
   a. Mostly ascomycetes, few zygomycetes and basidiomycetes
   b. Derivation of fungi determined by comparison of hyphae and asexual features
   c. Not officially classified as such due to lack of sexual reproductive structures
2. When sexual stage identified, may show two different names for different stages
3. As many as 17,000 species described fig 36.12

B. May Exhibit Parasexuality
   1. Provides a certain amount of genetic recombination
      a. Occurs after fusion of two strains forming heterokaryotic hyphae
      b. Exchange portions of chromosomes between genetically distinct nuclei within a common hyphae
   2. May be responsible for production of new strains of rusts

C. Economic Importance
   1. *Penicillium* species
      a. Produce penicillin antibiotic
      b. Flavor cheeses like Roquefort and Camembert
   2. *Aspergillus* species
      a. Ferment soy sauce and soy paste
      b. Produce citric acid under highly acidic conditions
   3. Some species of *Penicillium* and *Aspergillus* produce ascocarps on rare occasions
   4. Many other species are human and plant pathogens
      a. Include fungi that cause athlete's foot and ringworm
      b. *Fusarium* found widely on food
         1) Produces toxic trichothecenes, supposed agents of chemical warfare
         2) Dangerous agent of food spoilage
   5. *Aspergillus flavus* strains produce aflatoxins
      a. Extremely carcinogenic
      b. May be found on corn, peanuts, and other foods

36.3 Fungi form two key mutualistic symbiotic associations

I. LICHENS fig 36.13

A. Symbiotic Association Between Fungus and Photosynthesizer
   1. Example of mutualism, benefits both partners
   2. Mostly ascomycetes with green alga and/or cyanobacterium fig 36.14
      a. Specialized hyphae penetrate or envelop photosynthetic cells
      b. Fungal chemical signals direct algal special metabolism
      c. Photosynthetic partner held between interwoven fungal layers
         1) Not directly exposed to light, enough passes through
         2) Fungal layers are translucent
      d. Fungal partner cannot grow without photosynthetic partner
      e. Fungi protect algae from strong light and desiccation
   3. Ecology
      a. Inhabit cold, dry, generally harsh environments
      b. Help break rock surfaces and prepare habitat for other organisms
      c. Coloration of lichen protects photosynthetic partner

B. Lichens and Pollution
   1. Extremely sensitive to atmospheric pollutants
   2. Absorb substances dissolved in rain or dew
   3. Are absent in and around industrial cities

II. MYCORRHIZAE

A. Association of Plants and Fungi
   1. Most plant roots (90%) associated with certain fungi
      a. Functional extension of root system
         1) Increase amount of soil contact

2) Increase total surface area for absorption
b. Fungus aids in transfer of soil nutrients into roots
c. Plant provides organic carbon to fungus

2. Two types: Endomycorrhizae and ectomycorrhizae fig 36.15
a. Endomycorrhizae
1) Fungal hyphae penetrate outer cells of plant
2) Form coils, swellings, minute branches
3) Extend out into surrounding soil
b. Ectomycorrhizae
1) Hyphae surround but do not penetrate cell walls of roots
2) Mycelium extends far out into soil

B. Endomycorrhizae
1. More common of the two types
2. Generally a zygomycetes, 100 species associated with 200,000 plants
3. May increase yield of crops with lower phosphate and energy input
4. Early fossil plants exhibit association
a. May have aided plants in invading the land
b. Early soil lacking organic matter
c. Provide better growth in poor soils
d. Most primitive plants still depend greatly on mycorrhizae

C. Ectomycorrhizae fig 36.15b
1. Characteristic symbiont of trees and shrubs in temperate regions
2. Less common, mostly basidiomycetes, some ascomycetes
3. Several different fungi form associations with one plant
4. Different combinations have different physiological effects
5. Involve at least 5,000 species of fungi, many restricted to one plant species

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

It is important for the students to understand the uniqueness of fungal genetics and reproduction and the terminology associated with them. Fungi are unique in that even the largest mushrooms are no more than a mass of filaments. They do not exhibit extensive tissue differentiation or specific organs and organ systems as do plants and animals. For the most part, the only specialized cells in fungi are those associated with sexual or asexual reproductive processes.

Fungi fruit (produce reproductive structures) in response to various environmental stimuli including light. Nearly all fungi fruit above ground so that their spores are readily dispersed by the wind and rain. Truffles are an exception in that they fruit underground. They also produce chemicals similar to certain animal pheromones. Animals, especially pigs, are attracted to the odor of mature truffles, dig them up, and distribute the spores.

Discuss particularly common mushrooms found in your area. Stress the importance of knowing the identity of a mushroom before eating it. Some are hallucinogenic, others cause mild to serious gastrointestinal upsets. A few, the amanitas in particular, are deadly poisonous as they produce toxins that degrade RNA in the liver as it attempts to metabolize them. Symptoms of poisoning by these mushrooms do not show until four to five hours after ingestion, frequently too late for blood dialysis, currently the only treatment other than a complete liver transplant!

The caps of gill and pore fungi are always situated so that the basidial layer is perpendicular to the ground. Basidiospores are dependent on gravity to fall out of the gills or pores. Any intervening fungal tissue would defeat the reproductive process.

Predaceous fungi are extremely interesting. One species possesses a noose derived from specialized haustorium cells. When a nematode enters the noose and touches the cell wall, the noose contracts and traps it. The fungus then digests the nematode. Another form has cloverleaf-shaped sticky pads that attach to various soil organisms. Attempts are being made to culture such fungi on an agricultural level because soil nematodes destroy enormous amounts of commercial crops each year.

Discuss wheat rust and its primary and secondary hosts. Eradicating barberry bushes eliminates the second host and therefore the infection on the wheat crop. Several naturally rust-resistant strains of wheat have also recently been developed.

VISUAL RESOURCES:

Show slides, lots of them, illustrating the variety in shapes, forms, and color.

Bring in as many examples of fungi as you can. A greater variety are now available in grocery stores than ever before. These may include the Japanese *Shiitake* (black forest mushroom), *Pleurotus ostreatus* (oyster mushroom), *Auricularia* (ear fungus), dried morelles, and many chanterelles as well as the ever present *Agaricus campestris bisporus* (have two rather than four basidiospores).