CHAPTER 5

Fungi

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Overview

• Fungi are diverse and widespread

• They are essential for the well-being of most terrestrial ecosystems because they break down organic material and recycle vital nutrients

• Despite their diversity, fungi share key traits, most importantly the way in which they derive nutrition
Nutrition and Ecology

• Fungi are heterotrophs and absorb nutrients from outside of their body.

• Fungi use enzymes to break down a large variety of complex molecules into smaller organic compounds.

• Fungi exhibit diverse lifestyles:
  – Decomposers (Saprotrophs)
  – Parasites
  – Symbionts
Body Structure

• The most common body structures are multicellular filaments and single cells (yeasts)

• Some species grow as either filaments or yeasts; others grow as both
Morphology

• The morphology of multicellular fungi enhances their ability to absorb nutrients

• Fungi consist of mycelia, networks of branched hyphae adapted for absorption

• Most fungi have cell walls made of chitin
Reproductive structure

Hyphae

Spore-producing structures

Mycelium

20 µm
• Some fungi have hyphae divided into cells by **septa**, with pores allowing cell-to-cell movement of organelles

• **Coenocytic fungi** lack septa
(a) Septate hypha

(b) Coenocytic hypha
(a) Septate hypha
(b) Coenocytic hypha
Specialized Hyphae in Mycorrhizal Fungi

- Some unique fungi have specialized hyphae called **haustoria (giác mút)** that allow them to penetrate the tissues of their host
(a) Hyphae adapted for trapping and killing prey
(b) Haustoria
• **Mycorrhizae** are mutually beneficial relationships between fungi and plant roots

• **Ectomycorrhizal fungi** form sheaths of hyphae over a root and also grow into the extracellular spaces of the root cortex

• **Arbuscular mycorrhizal fungi** extend hyphae through the cell walls of root cells and into tubes formed by invagination of the root cell membrane
Reproduction

- Fungi propagate themselves by producing vast numbers of **spores**, either sexually or asexually
- Fungi can produce spores from different types of life cycles
Sexual Reproduction

- Fungal nuclei are normally haploid, with the exception of transient diploid stages formed during the sexual life cycles.

- Sexual reproduction requires the fusion of hyphae from different mating types.

- Fungi use sexual signaling molecules called **pheromones** to communicate their mating type.
• **Plasmogamy** is the union of two parent mycelia

• In most fungi, the haploid nuclei from each parent do not fuse right away; they coexist in the mycelium, called a **heterokaryon**

• In some fungi, the haploid nuclei pair off two to a cell; such a mycelium is said to be **dikaryotic**
• Hours, days, or even centuries may pass before the occurrence of **karyogamy**, nuclear fusion

• During karyogamy, the haploid nuclei fuse, producing diploid cells

• The diploid phase is short-lived and undergoes meiosis, producing haploid spores
Spores

Spore-producing structures

ASEXUAL REPRODUCTION

Mycelium

GERMINATION

Key

- **Haploid** ($n$)
- **Heterokaryotic** (unfused nuclei from different parents)
- **Diploid** ($2n$)
Spores
Spore-producing structures
Mycelium
Heterokaryotic stage
Plasmogamy (fusion of cytoplasm)
Karyogamy (fusion of nuclei)
Zygote

Key:
- Haploid (n)
- Heterokaryotic (unfused nuclei from different parents)
- Diploid (2n)

Asexual reproduction
- Germination

Sexual reproduction
- Spores
- Mycelium
Spores

Spore-producing structures

Mycelium

Heterokaryotic stage

PLASMOGAMY (fusion of cytoplasm)

KARYOGAMY (fusion of nuclei)

Zygote

SEXUAL REPRODUCTION

Diploid (2n)

Haploid (n)

Heterokaryotic (unfused nuclei from different parents)

Key

Spores

ASEXUAL REPRODUCTION

GERMINATION

MEIOSIS

GERMINATION

Spores
Asexual Reproduction

• In addition to sexual reproduction, many fungi can reproduce asexually

• **Molds** produce haploid spores by mitosis and form visible mycelia
• Other fungi that can reproduce asexually are yeasts, which inhabit moist environments.

• Instead of producing spores, yeasts reproduce asexually by simple cell division and the pinching of “bud cells” from a parent cell.
10 µm

Parent cell

Bud
• Many molds and yeasts have no known sexual stage

• Mycologists have traditionally called these **deuteromycetes**, or imperfect fungi
Fungal diversity

• Molecular analyses have helped clarify evolutionary relationships among fungal groups, although areas of uncertainty remain
The phylogeny of fungi

- Chytrids
- Zygote fungi
- Arbuscular mycorrhizal fungi
- Sac fungi
- Club fungi

Chytridiomycota
Zygomycota
Glomeromycota
Ascomycota
Basidiomycota
Chytrids (1,000 species)

Hyphae

25 µm
Zygomycetes (1,000 species)
Glomeromycetes (160 species)
Ascomycetes (65,000 species)
Basidiomycetes (30,000 species)
Chytrids

- **Chytrids** (phylum Chytridiomycota) are found in freshwater and terrestrial habitats
- They can be decomposers, parasites, or mutualists
- Molecular evidence supports the hypothesis that chytrids diverged early in fungal evolution
- Chytrids are unique among fungi in having flagellated spores, called **zoospores**
Flagellum

4 µm
• Until recently, systematists thought that fungi lost flagella only once in their evolutionary history

• Molecular data indicate that some “chytrids” are actually more closely related to another fungal group, the zygomycetes; chytrids are a paraphyletic group
Zygomycetes

• The **zygomycetes** (phylum Zygomycota) exhibit great diversity of life histories

• They include fast-growing molds, parasites, and commensal symbionts

• The zygomycetes are named for their sexually produced **zygosporangia**

• Zygosporangia, which are resistant to freezing and drying, can survive unfavorable conditions
• The life cycle of black bread mold (*Rhizopus stolonifer*) is fairly typical of the phylum
Rhizopus growing on bread

Key:
- Haploid (n)
- Heterokaryotic (n + n)
- Diploid (2n)

SEXUAL REPRODUCTION

Mating type (+) → Mating type (-) → Gametangia with haploid nuclei → Young zygosporangium (heterokaryotic) → PLASMOGAMY
The diagram illustrates the life cycle of Rhizopus, a type of mold. The cycle includes the following stages:

1. **Gametangia with haploid nuclei**: This stage involves the formation of gametangia, which contain haploid nuclei.
2. **Mating type (+)** and **Mating type (−)**: These are two different mating types that can fuse to form a heterokaryotic cell.
3. **Plasmogamy**: The fusion of the two mating types results in a heterokaryotic cell.
4. **Karyogamy**: The nuclei from the two mating types fuse to form diploid nuclei.
5. **Meiosis**: The diploid nuclei undergo meiosis to produce haploid spores.
6. **Sporangium**: The haploid spores develop into sporangia, completing the cycle.

The key to the diagram indicates:

- **Haploid (n)**
- **Heterokaryotic (n + n)**
- **Diploid (2n)**

**Rhizopus growing on bread**

**100 μm**

The diagram also includes pictures of Rhizopus growing on bread and sporangia, providing a visual representation of the process.
Rhizopus growing on bread

Key:
- Haploid (n)
- Heterokaryotic (n + n)
- Diploid (2n)

Plasmogamy

Sporangia

Asexual reproduction

Mycelium

Dispersal and germination

Sporangium

Dispersal and germination

Sporangia

Asexual reproduction

Spores

Dispersal and germination

Young zygosporangium (heterokaryotic)

Karyogamy

Zygosporangium

Gametangia with haploid nuclei

Mating type (+)

Mating type (-)

Sexual reproduction

Meiosis

50 μm

100 μm
Some zygomycetes, such as *Pilobolus*, can actually “aim” their sporangia toward conditions associated with good food sources.
Glomeromycetes

• The glomeromycetes (phylum Glomeromycota) were once considered zygomycetes

• They are now classified in a separate clade

• Glomeromycetes form arbuscular mycorrhizae
Ascomycetes

- **Ascomycetes** (phylum Ascomycota) live in marine, freshwater, and terrestrial habitats.

- The phylum is defined by production of sexual spores in saclike **asci**, usually contained in fruiting bodies called **ascocarps**.

- Ascomycetes are commonly called **sac fungi**.

- Ascomycetes vary in size and complexity from unicellular yeasts to elaborate cup fungi and morels.
Morchella esculenta, the tasty morel
Tuber melanosporum, a truffle
Aspergillus
• Ascomycetes include plant pathogens, decomposers, and symbionts

• Ascomycetes reproduce asexually by enormous numbers of asexual spores called conidia

• Conidia are not formed inside sporangia; they are produced asexually at the tips of specialized hyphae called conidiophores

• *Neurospora* is a model organism with a well-studied genome
Neurospora crassa
Basidiomycetes

• **Basidiomycetes** (phylum Basidiomycota) include mushrooms, puffballs, and shelf fungi, mutualists, and plant parasites

• The phylum is defined by a clublike structure called a **basidium**, a transient diploid stage in the life cycle

• The basidiomycetes are also called **club fungi**
Maiden veil fungus (*Dictyphora*)
Puffballs
Puffballs emitting spores
Sheft fungi
Amanita
Tremella
Roles of Fungi

• Fungi play key roles in nutrient cycling, ecological interactions, and human welfare

• Fungi interact with other organisms in many ways
Fungi as Decomposers

• Fungi are efficient decomposers

• They perform essential recycling of chemical elements between the living and nonliving world
Fungi as Mutualists

• Fungi form mutualistic relationships with plants, algae, cyanobacteria, and animals

• All of these relationships have profound ecological effects
Fungus-Plant Mutualisms

• Mycorrhizae are enormously important in natural ecosystems and agriculture

• Plants harbor harmless symbiotic endophytes that live inside leaves or other plant parts

• Endophytes make toxins that deter herbivores and defend against pathogens
Fungus-Animal Symbioses

- Some fungi share their digestive services with animals
- These fungi help break down plant material in the guts of cows and other grazing mammals
- Many species of ants and termites use the digestive power of fungi by raising them in “farms”
Lichens

- A lichen is a symbiotic association between a photosynthetic microorganism and a fungus in which millions of photosynthetic cells are held in a mass of fungal hyphae
A fruticose (shrublike) lichen
Crustose (encrusting) lichens
A foliose (leaflike) lichen
• The fungal component of a lichen is most often an ascomycete

• Algae or cyanobacteria occupy an inner layer below the lichen surface
• The algae provide carbon compounds, cyanobacteria provide organic nitrogen, and fungi provide the environment for growth

• The fungi of lichens can reproduce sexually and asexually

• Asexual reproduction is by fragmentation or the formation of *soredia*, small clusters of hyphae with embedded algae
• Lichens are important pioneers on new rock and soil surfaces

• Lichens are sensitive to pollution, and their death can be a warning that air quality is deteriorating
Fungi as Pathogens

- About 30% of known fungal species are parasites or pathogens, mostly on or in plants.
- Some fungi that attack food crops are toxic to humans.
- Animals are much less susceptible to parasitic fungi than are plants.
- The general term for a fungal infection in animals is *mycosis*.
(a) Corn smut on corn
(b) Tar spot fungus on maple leaves
(c) Ergots on rye
Practical Uses of Fungi

• Humans eat many fungi and use others to make cheeses, alcoholic beverages, and bread

• Some fungi are used to produce antibiotics for the treatment of bacterial infections, for example the ascomycete *Penicillium*

• Genetic research on fungi is leading to applications in biotechnology
  – For example, insulin-like growth factor can be produced in the fungus *Saccharomyces cerevisiae*
Penicillium
Staphylococcus

Penicillium

Zone of inhibited growth