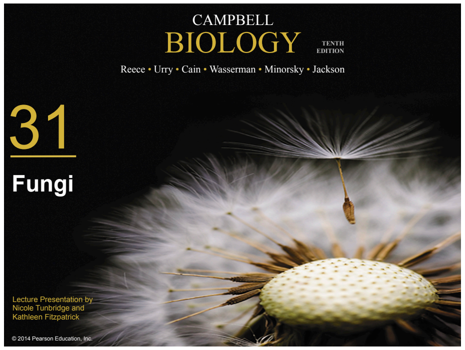

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Mighty Mushrooms

- 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
- About 100,000 species of fungi have been described
- It is estimated there are actually 1.5 million species of fungi

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Figure 31.1

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Figure 31.1a

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Concept 31.1: Fungi are heterotrophs that feed by absorption

- Despite their diversity, fungi share key traits, most importantly the way in which they derive nutrition

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Nutrition and Ecology

- Fungi are heterotrophs and absorb nutrients from outside of their bodies
- Fungi use enzymes to break down a large variety of complex molecules into smaller organic compounds
- The versatility of these enzymes contributes to fungi's ecological success

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- Fungi exhibit diverse lifestyles
  - Decomposers
  - Parasites
  - Mutualists

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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

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- The morphology of multicellular fungi enhances their ability to absorb nutrients
- Fungi consist of **mycelia**, networks of branched **hyphae** adapted for absorption
- A mycelium's structure maximizes its surface-to-volume ratio
- Fungal cell walls contain **chitin**

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Figure 31.2

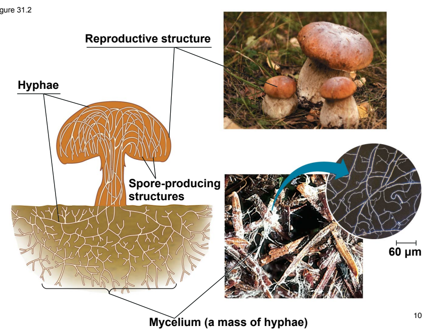

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Figure 31.2a

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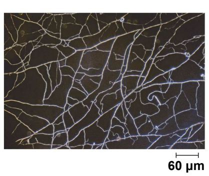

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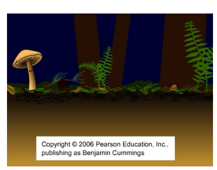
Animation: Fungal Reproduction and Nutrition



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- Most fungi have hyphae divided into cells by **septa**, with pores allowing cell-to-cell movement of organelles
- **Coenocytic fungi** lack septa and have a continuous cytoplasmic mass with hundreds or thousands of nuclei

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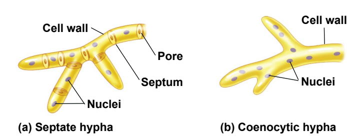
Figure 31.3



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Specialized Hyphae in Mycorrhizal Fungi

- Some unique fungi have specialized hyphae called **haustoria** that allow them to penetrate the tissues of their host

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Figure 31.4

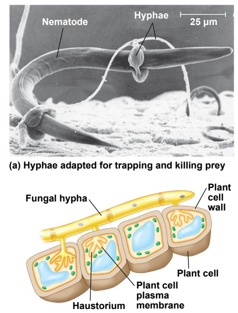

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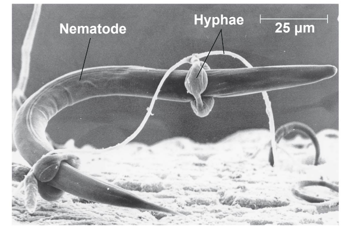
Figure 31.4a



(a) Hyphae adapted for trapping and killing prey

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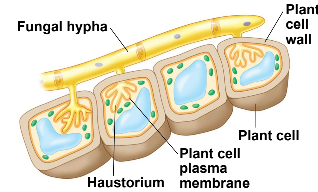
Figure 31.4b



(b) Haustoria

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- **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

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- Mycorrhizal fungi deliver phosphate ions and minerals to plants
- Most vascular plants have mycorrhizae
- Mycorrhizal fungi colonize soils by the dispersal of haploid cells called **spores**

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Concept 31.2: Fungi produce spores through sexual or asexual life cycles

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

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Figure 31.5-1

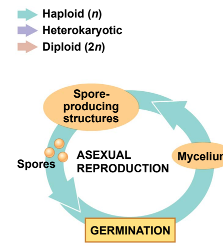

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Figure 31.5-2

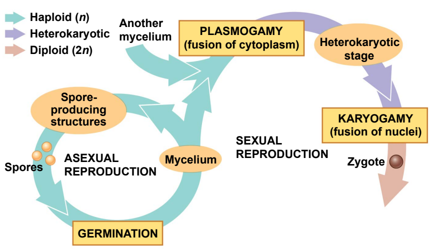

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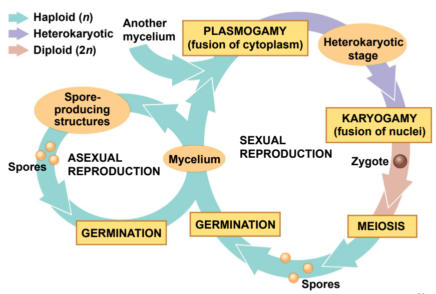
Figure 31.5-3



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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

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- **Plasmogamy** is the union of cytoplasm from 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**

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- 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
- The paired processes of karyogamy and meiosis produce genetic variation

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Asexual Reproduction

- In addition to sexual reproduction, many fungi can reproduce asexually
- **Molds** produce haploid spores by mitosis and form visible mycelia

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Figure 31.6

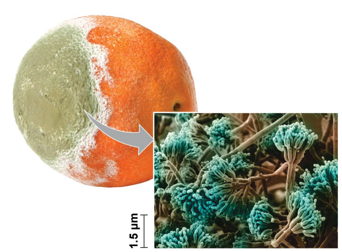

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Figure 31.6a

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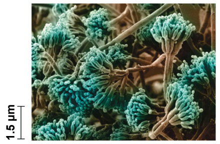
Figure 31.6b



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- Other fungi that can reproduce asexually are yeasts, which are single cells
- Instead of producing spores, yeasts reproduce asexually by simple cell division and the pinching of "bud cells" from a parent cell
- Some fungi can grow as yeasts and as filamentous mycelia

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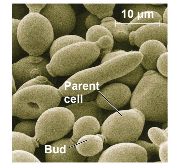
Figure 31.7



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- Many molds and yeasts have no known sexual stage
- Mycologists have traditionally called these **deuteromycetes**
- These fungi are reclassified once their sexual stage is discovered
- Mycologists can now also use genomic techniques to classify fungi

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Concept 31.3: The ancestor of fungi was an aquatic, single-celled, flagellated protist

- Fungi and animals are more closely related to each other than they are to plants or other eukaryotes

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The Origin of Fungi

- Fungi, animals, and their protistan relatives form the **opisthokonts** clade

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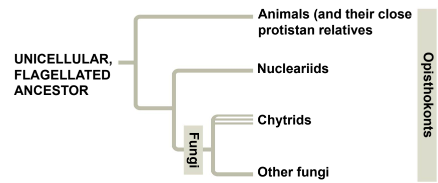
Figure 31.8



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- DNA evidence suggests that
  - Fungi are most closely related to unicellular **nucleariids**
  - Animals are most closely related to unicellular choanoflagellates
- This suggests that multicellularity arose separately in animals and fungi
- The oldest undisputed fossils of fungi are only about 460 million years old

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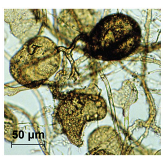
Figure 31.9



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Early-Diverging Fungal Groups

- Genomic studies have identified chytrids in the genus *Rozella* as an early diverging fungal lineage
- *Rozella* and other members of the unicellular group, "cryptomycota" lack chitin-rich cell walls

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The Move to Land

- Fungi were among the earliest colonizers of land
- Fossil evidence indicates fungi formed mutualistic relationships with early land plants
- Genomic analysis indicates genes involved in mycorrhizal formation, *sym* genes, were likely present in the common ancestor to land plants

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Concept 31.4: Fungi have radiated into a diverse set of lineages

- Molecular analyses have helped clarify evolutionary relationships among fungal groups, although areas of uncertainty remain
- Recent metagenomic studies estimate fungal diversity at around 1.5 million species

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Figure 31.10

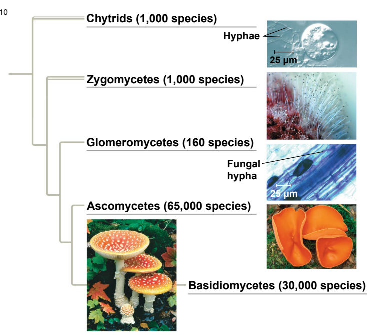

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Figure 31.10a

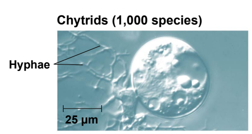

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Figure 31.10b

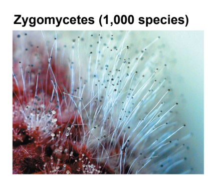

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Figure 31.10c

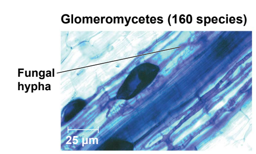

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Figure 31.10d

Ascomycetes (65,000 species)

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Figure 31.10e

Basidiomycetes (30,000 species)

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Chytrids

- **Chytrids** (phylum Chytridiomycota) are found in terrestrial, freshwater, and marine habitats including hydrothermal vents
- 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**

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Figure 31.UN02

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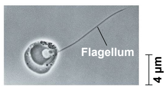
Figure 31.11



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Video: *Allomyces* Zoospore Release

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Video: *Phlyctochytrium* Zoospore Release

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Zygomycetes

- The **zygomycetes** (phylum Zygomycota) exhibit great diversity of life histories
- They include fast-growing molds, parasites, and commensal symbionts
- The life cycle of black bread mold (*Rhizopus stolonifer*) is fairly typical of the phylum
- Its hyphae are coenocytic
- Asexual sporangia produce haploid spores

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Figure 31.UN03

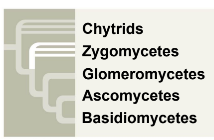

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Figure 31.12

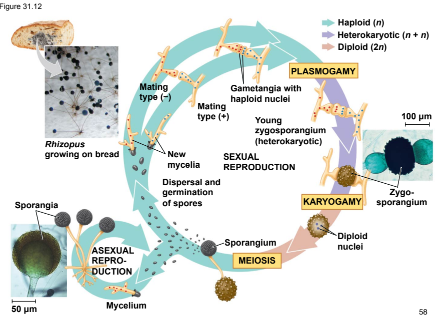

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Figure 31.12a

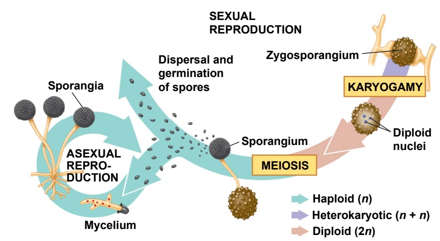

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Figure 31.12b

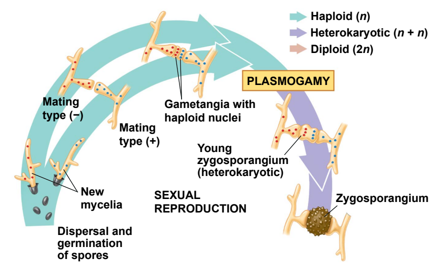

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Figure 31.12c

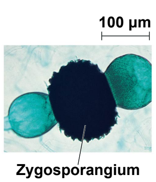

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Figure 31.12d

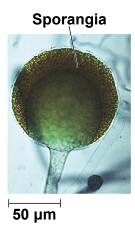

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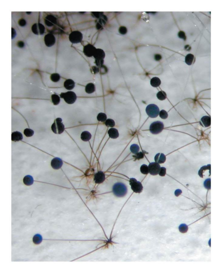
Figure 31.12e



Rhizopus growing on bread

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Figure 31.12f

Rhizopus growing on bread

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- The zygomycetes are named for their sexually produced **zygosporangia**
- Zygosporangia are the site of karyogamy and then meiosis
- Zygosporangia, which are resistant to freezing and drying, can survive unfavorable conditions
- Some zygomycetes, such as *Pilobolus,* can actually "aim" and shoot their sporangia toward bright light

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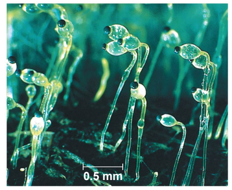
Figure 31.13



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Glomeromycetes

- The **glomeromycetes** (phylum Glomeromycota) were once considered zygomycetes
- They are now classified in a separate clade
- Glomeromycetes form arbuscular mycorrhizae

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Figure 31.UN04

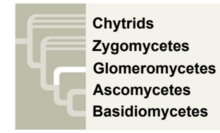

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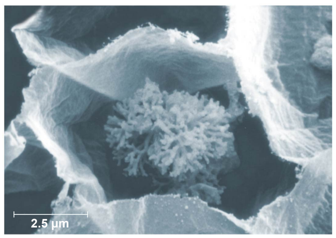
Figure 31.14



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Ascomycetes

- **Ascomycetes** (phylum Ascomycota) live in marine, freshwater, and terrestrial habitats
- Ascomycetes produce sexual spores in saclike **asci** 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

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Figure 31.UN05

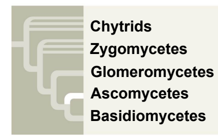

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Figure 31.15

Morchella esculenta *Tuber melanosporum*

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Figure 31.15a

Morchella esculenta

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Figure 31.15b

Tuber melanosporum

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- 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 crassa*, a bread mold, is a model organism with a well-studied genome

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Figure 31.16

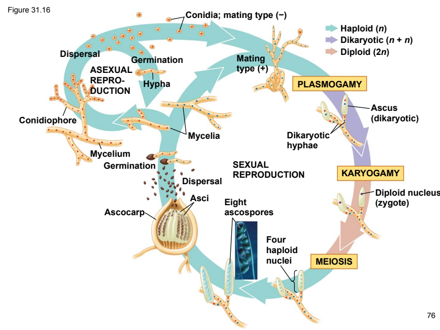

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Figure 31.16a

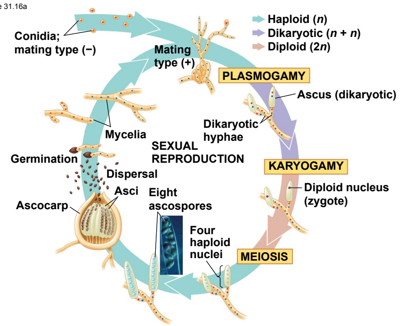

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Figure 31.16b

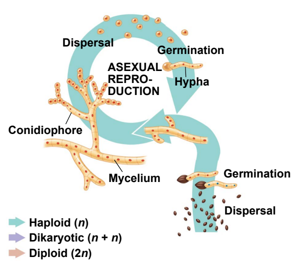

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Figure 31.16c

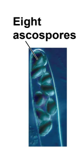

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Table 31.1

Table 31.1 Comparison of Gene Density in *Neurospora, Drosophila,* and *Homo sapiens*

	Genome Size (million base pairs)	Number of Genes	Gene Density (genes per million base pairs)
Neurospora crassa (ascomycete fungus)	41	9,700	236
Drosophila melanogaster (fruit fly)	165	14,000	85
Homo sapiens (human)	3,000	<21,000	7

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Basidiomycetes

- **Basidomycetes** (phylum Basidiomycota) include mushrooms, puffballs, and shelf fungi
- Some basidiomycetes form mycorrhizae, and others are 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
- Many basidiomycetes are decomposers of wood

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Figure 31.UN06

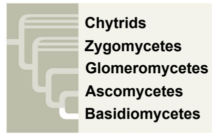

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Figure 31.17

Puffballs

Shelf fungi

Maiden veil fungus

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Figure 31.17a

Shelf fungi

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Puffballs

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Maiden veil fungus

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- The life cycle of a basidiomycete usually includes a long-lived dikaryotic mycelium
- In response to environmental stimuli, the mycelium reproduces sexually by producing elaborate fruiting bodies called **basidiocarps**
- Mushrooms are examples of basidiocarps
- The numerous basidia in a basidiocarp are sources of sexual spores called basidiospores

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Figure 31.18

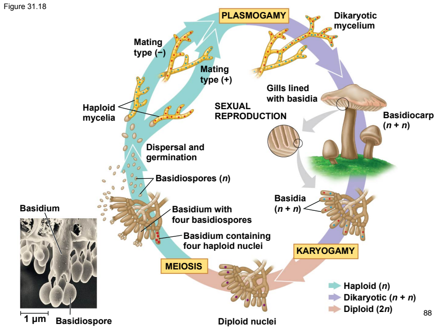

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Figure 31.18a

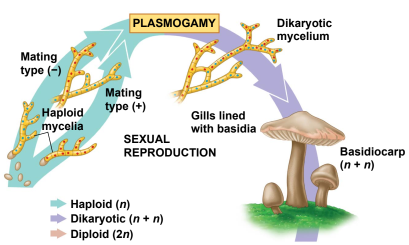

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Figure 31.18b

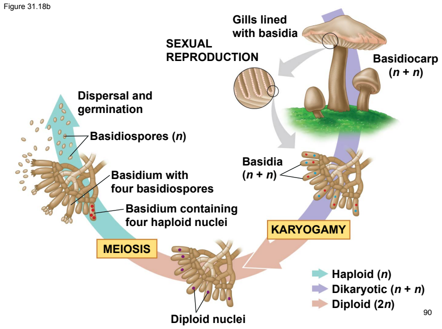

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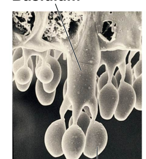
Figure 31.18c

Basidium



1 µm Basidiospore

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- Basidiomycetes can produce mushrooms quickly
- Some species may produce "fairy rings"

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Figure 31.19

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Concept 31.5: Fungi play key roles in nutrient cycling, ecological interactions, and human welfare

- Fungi interact with other organisms as decomposers, mutualists, and pathogens

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Fungi as Decomposers

- Fungi are efficient decomposers of organic material including cellulose and lignin
- They perform essential recycling of chemical elements between the living and nonliving world

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Fungi as Mutualists

- Fungi form mutualistic relationships with plants, algae, cyanobacteria, and animals
- All of these relationships have profound ecological effects

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Fungus-Plant Mutualisms

- Mycorrhizae are enormously important in natural ecosystems and agriculture
- Plants harbor harmless symbiotic **endophytes**, fungi that live inside leaves or other plant parts
- Endophytes make toxins that deter herbivores and defend against pathogens
- Most endophytes are ascomycetes

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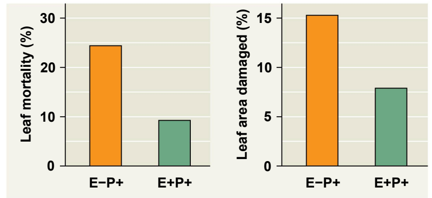
Figure 31.20

Results

Endophyte not present; pathogen present (E−P+)
Both endophyte and pathogen present (E+P+)



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Fungus-Animal Mutualisms

- 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 use the digestive power of fungi by raising them in “farms”

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Figure 31.21

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Lichens

- A **lichen** is a symbiotic association between a photosynthetic microorganism and a fungus
- Millions of photosynthetic cells are held in a mass of fungal hyphae
- The photosynthetic component is green algae or cyanobacteria
- The fungal component is most often an ascomycete

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Figure 31.22

A fruticose (shrublike) lichen

A foliose (leaflike) lichen

Crustose (encrusting) lichens

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Figure 31.22a

A fruticose (shrublike) lichen

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Figure 31.22b

A foliose (leaflike) lichen

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Figure 31.22c

Crustose (encrusting) lichens

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- The symbioses are so complete that lichens are given scientific names
- Algae or cyanobacteria occupy an inner layer below the lichen surface

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Figure 31.23

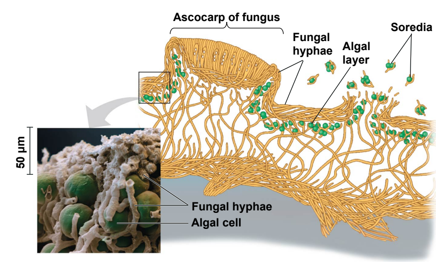

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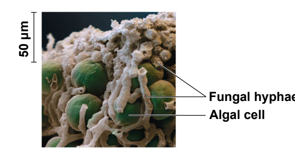
Figure 31.23a



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- The algae provide carbon compounds, cyanobacteria also 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

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- Lichens are important pioneers on new rock and soil surfaces
- Lichens were on land 420 million years ago, and these early lichens may have modified rocks and soil much as they do today, helping pave the way for plants

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Fungi as Parasites

- About 30% of known fungal species are parasites or pathogens, mostly on or in plants
- Each year, 10% to 50% of the world’s fruit harvest is lost due to fungi
- Some fungi that attack food crops are toxic to humans

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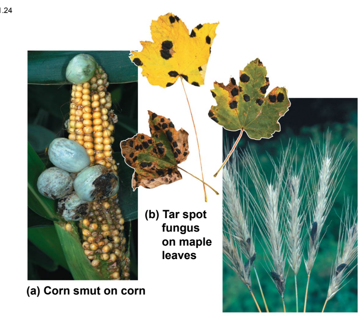
Figure 31.24



(a) Corn smut on corn

(b) Tar spot fungus on maple leaves

(c) Ergots on rye

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Figure 31.24a

(a) Corn smut on corn

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Figure 31.24b

(b) Tar spot fungus on maple leaves

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Figure 31.24c

(c) Ergots on rye

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- Ergot of rye is caused by an ascomycete, and produces toxins
- More than 40,000 people died from an epidemic of ergotism during the middle ages
- Ergotism is characterized by gangrene, nervous spasms, burning sensations, hallucinations, and temporary insanity
- Ergots contain lysergic acid, the raw material for LSD

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- Animals are much less susceptible to parasitic fungi than are plants
- The chytrid *Batrachochytrium dendrobatidis* might be the cause of the recent decline in amphibians worldwide

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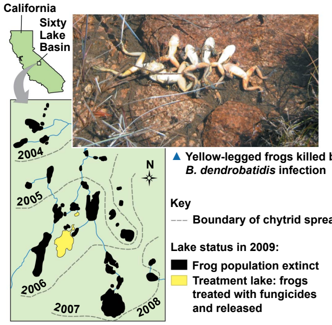
Figure 31.25



▲ Yellow-legged frogs killed by *B. dendrobatidis* infection

Key

Boundary of chytrid spread

Lake status in 2009:

Frog population extinct

Treatment lake: frogs treated with fungicides and released

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Figure 31.25a

Yellow-legged frogs killed by *B. dendrobatidis* infection

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- The general term for a fungal infection in animals is **mycosis**
- Ringworm and athlete's foot are examples of human mycoses
- Systemic mycoses spread through the body
  - For example, coccidioidomycosis produces tuberculosis-like symptoms
- Some mycoses are opportunistic
  - For example, *Candida albicans*, which causes yeast infections

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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*

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- Genetic research on fungi is leading to applications in biotechnology
  - For example, scientists are using *Saccharomyces* to study homologs of the genes involved in Parkinson's and Huntington's diseases
  - For example, insulin-like growth factor can be produced in the fungus *Saccharomyces cerevisiae*
  - For example, *Gliocladium roseum*, a fungus that produces hydrocarbons similar to diesel fuel, could be used to produce biofuels

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Figure 31.26

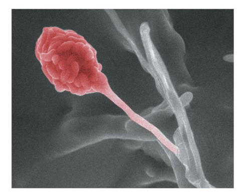

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Figure 31.UN01a

Table 1. Numbers of Genes in *L. bicolor* and Four Nonmycorrhizal Fungal Species

	L. bicolor	1	2	3	4
Protein-coding genes	20,614	13,544	10,048	7,302	6,522
Genes for membrane transporters	505	412	471	457	386
Genes for small secreted proteins (SSPs)	2,191	838	163	313	58

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Figure 31.UN01b

Table 2. *L. bicolor* Genes Most Highly Upregulated in Ecto-mycorrhizal Mycelium (ECM) of Douglas Fir or Poplar vs. Free-Living Mycelium (FLM)

Protein ID	Protein Feature or Function	Douglas Fir ECM/FLM Ratio	Poplar ECM/FLM Ratio
298599	Small secreted protein	22,877	12,913
293826	Enzyme inhibitor	14,750	17,069
333839	Small secreted protein	7,844	1,931
316764	Enzyme	2,760	1,478

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Figure 31.UN01c

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Figure 31.UN07

Fungal Phylum	Distinguishing Features
Chytridiomycota (chytrids)	Flagellated spores
Zygomycota (zygomycetes)	Resistant zygosporangium as sexual stage
Glomeromycota (arbuscular mycorrhizal fungi)	Arbuscular mycorrhizae formed with plants
Ascomycota (ascomycetes)	Sexual spores (ascospores) borne internally in sacs called asci; vast numbers of asexual spores (conidia) produced
Basidiomycota (basidiomycetes)	Elaborate fruiting body (basidiocarp) containing many basidia that produce sexual spores (basidiospores)

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Figure 31.UN08

Soil Temp.	*Curvularia* + or –	Plant Mass (g)	No. of New Shoots
30°C	E–	16.2	32
	E+	22.8	60
35°C	E–	21.7	43
	E+	28.4	60
40°C	E–	8.8	10
	E+	22.2	37
45°C	E–	0	0
	E+	15.1	24

Source: R. S. Redman et al., Thermotolerance generated by plant/fungal symbiosis, *Science* 298: 1581 (2002).

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Figure 31.UN09

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