Fungus

A fungus ([/ˈfʌŋɡəs/](https://en.wikipedia.org/wiki/Help:IPA_for_English); [plural](https://en.wikipedia.org/wiki/Plural): fungi or funguses) is any member of the group of [eukaryotic](https://en.wikipedia.org/wiki/Eukaryote) organisms that includes unicellular microorganisms such as [yeasts](https://en.wikipedia.org/wiki/Yeast) and [molds](https://en.wikipedia.org/wiki/Mold), as well as multicellular fungi that produce familiar fruiting forms known as [mushrooms](https://en.wikipedia.org/wiki/Mushrooms). These organisms are classified as a [kingdom](https://en.wikipedia.org/wiki/Kingdom_(biology)), Fungi, which is separate from the other eukaryotic life kingdoms of [plants](https://en.wikipedia.org/wiki/Plants) and [animals](https://en.wikipedia.org/wiki/Animals).

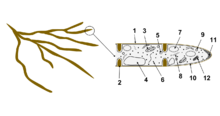
The fungus kingdom encompasses an enormous diversity of [taxa](https://en.wikipedia.org/wiki/Taxon" \o "Taxon) with varied ecologies, [life cycle](https://en.wikipedia.org/wiki/Biological_life_cycle) strategies, and [morphologies](https://en.wikipedia.org/wiki/Morphology_(biology)) ranging from unicellular aquatic [chytrids](https://en.wikipedia.org/wiki/Chytrid" \o "Chytrid) to large mushrooms. However, little is known of the true [biodiversity](https://en.wikipedia.org/wiki/Biodiversity) of Kingdom Fungi, which has been estimated at 1.5 million to 5 million species, with about 5% of these having been formally classified. Ever since the pioneering 18th and 19th century [taxonomical](https://en.wikipedia.org/wiki/Taxonomy_(biology)) works of [Carl Linnaeus](https://en.wikipedia.org/wiki/Carl_Linnaeus), [Christian Hendrik Persoon](https://en.wikipedia.org/wiki/Christian_Hendrik_Persoon), and [Elias Magnus Fries](https://en.wikipedia.org/wiki/Elias_Magnus_Fries), fungi have been [classified](https://en.wikipedia.org/wiki/Biological_classification) according to their morphology (e.g., characteristics such as spore color or microscopic features) or [physiology](https://en.wikipedia.org/wiki/Physiology). Advances in [molecular genetics](https://en.wikipedia.org/wiki/Molecular_genetics) have opened the way for [DNA analysis](https://en.wikipedia.org/wiki/DNA_sequencing) to be incorporated into taxonomy, which has sometimes challenged the historical groupings based on morphology and other traits. [Phylogenetic](https://en.wikipedia.org/wiki/Phylogenetic" \o "Phylogenetic) studies published in the last decade have helped reshape the classification within Kingdom Fungi, which is divided into one [subkingdom](https://en.wikipedia.org/wiki/Taxonomic_rank), seven [phyla](https://en.wikipedia.org/wiki/Phylum), and ten subphyla.

Abundant worldwide, most fungi are inconspicuous because of the small size of their structures, and their [cryptic](https://en.wikipedia.org/wiki/Crypsis" \o "Crypsis)lifestyles in soil, on dead matter. They are both [symbionts](https://en.wikipedia.org/wiki/Symbiosis" \o "Symbiosis) of plants, animals, or other fungi and also [parasites](https://en.wikipedia.org/wiki/Parasites). They may become noticeable when [fruiting](https://en.wikipedia.org/wiki/Sporocarp_(fungi)), either as mushrooms or as molds. Fungi perform an essential role in the decomposition of organic matter and have fundamental roles in [nutrient cycling](https://en.wikipedia.org/wiki/Biogeochemical_cycle) and exchange in the environment. They have long been used as a direct source of food, in the form of mushrooms and [truffles](https://en.wikipedia.org/wiki/Tuber_(genus)), as a [leavening](https://en.wikipedia.org/wiki/Bread#Leavening) agent for bread, in the [fermentation](https://en.wikipedia.org/wiki/Fermentation_(food)) of various food products, such as [wine](https://en.wikipedia.org/wiki/Wine), [beer](https://en.wikipedia.org/wiki/Beer), and [soy sauce](https://en.wikipedia.org/wiki/Soy_sauce). Since the 1940s, fungi have been used for the production of [antibiotics](https://en.wikipedia.org/wiki/Antibiotic), and, more recently, various [enzymes](https://en.wikipedia.org/wiki/Enzyme) produced by fungi are used[industrially](https://en.wikipedia.org/wiki/Enzyme#Industrial_applications) and in [detergents](https://en.wikipedia.org/wiki/Protease#Occurrence). Fungi are also used as [biological pesticides](https://en.wikipedia.org/wiki/Biological_pesticide) to control weeds, plant diseases and insect pests. Many species produce [bioactive](https://en.wikipedia.org/wiki/Bioactive) compounds called [mycotoxins](https://en.wikipedia.org/wiki/Mycotoxin" \o "Mycotoxin), such as [alkaloids](https://en.wikipedia.org/wiki/Alkaloid) and [polyketides](https://en.wikipedia.org/wiki/Polyketide" \o "Polyketide), that are toxic to animals including humans. The fruiting structures of a few species contain [psychotropic](https://en.wikipedia.org/wiki/Psychotropic) compounds and are consumed [recreationally](https://en.wikipedia.org/wiki/Recreational_drug_use) or in traditional [spiritual ceremonies](https://en.wikipedia.org/wiki/Entheogens). Fungi can break down manufactured materials and buildings, and become significant [pathogens](https://en.wikipedia.org/wiki/Pathogenic_fungi) of humans and other animals. Losses of crops due to fungal diseases (e.g., [rice blast disease](https://en.wikipedia.org/wiki/Rice_blast_disease)) or food [spoilage](https://en.wikipedia.org/wiki/Spoilage) can have a large impact on human [food supplies](https://en.wikipedia.org/wiki/Food_security) and local economies.

## Etymology

The English word *fungus* is directly adopted from the [Latin](https://en.wikipedia.org/wiki/Latin) *fungus* (mushroom), used in the writings of [Horace](https://en.wikipedia.org/wiki/Horace) and [Pliny](https://en.wikipedia.org/wiki/Pliny_the_Elder).[[5]](https://en.wikipedia.org/wiki/Fungus#cite_note-Simpson1979-5) This in turn is derived from the [Greek](https://en.wikipedia.org/wiki/Ancient_Greek) word*sphongos* (σφογγος "sponge"), which refers to the [macroscopic](https://en.wikipedia.org/wiki/Macroscopic) structures and morphology of mushrooms and molds;[[6]](https://en.wikipedia.org/wiki/Fungus#cite_note-Ainsworth2-6) the root is also used in other languages, such as the German *Schwamm* ("sponge") and *Schimmel* ("mold").[[7]](https://en.wikipedia.org/wiki/Fungus#cite_note-Mitzka1960-7) The use of the word *mycology*, which is derived from the Greek *mykes* (μύκης "mushroom") and*logos* (λόγος "discourse"),[[8]](https://en.wikipedia.org/wiki/Fungus#cite_note-8) to denote the scientific study of fungi is thought to have originated in 1836 with English naturalist [Miles Joseph Berkeley](https://en.wikipedia.org/wiki/Miles_Joseph_Berkeley)'s publication*The English Flora of Sir James Edward Smith, Vol. 5.*[[6]](https://en.wikipedia.org/wiki/Fungus#cite_note-Ainsworth2-6) A group of all the fungi present in a particular area or geographic region is known as [mycobiota](https://en.wikipedia.org/wiki/Mycobiota" \o "Mycobiota) (plural noun, no singular), e.g., "the mycobiota of Ireland".[[9]](https://en.wikipedia.org/wiki/Fungus#cite_note-9)

## Characteristics

[](https://en.wikipedia.org/wiki/File:HYPHAE.png)

**Fungal hyphae cells**

1. Hyphal wall
2. [Septum](https://en.wikipedia.org/wiki/Septum)
3. [Mitochondrion](https://en.wikipedia.org/wiki/Mitochondrion)
4. [Vacuole](https://en.wikipedia.org/wiki/Vacuole)
5. [Ergosterol](https://en.wikipedia.org/wiki/Ergosterol) crystal
6. [Ribosome](https://en.wikipedia.org/wiki/Ribosome)
7. Nucleus
8. [Endoplasmic reticulum](https://en.wikipedia.org/wiki/Endoplasmic_reticulum)
9. [Lipid body](https://en.wikipedia.org/wiki/Lipid_body)
10. [Plasma membrane](https://en.wikipedia.org/wiki/Plasma_membrane)
11. [Spitzenkörper](https://en.wikipedia.org/wiki/Spitzenk%C3%B6rper)
12. [Golgi apparatus](https://en.wikipedia.org/wiki/Golgi_apparatus)

Before the introduction of [molecular methods](https://en.wikipedia.org/wiki/Molecular_phylogenetics) for phylogenetic analysis, [taxonomists](https://en.wikipedia.org/wiki/Taxonomy_(biology)) considered fungi to be members of the[plant kingdom](https://en.wikipedia.org/wiki/Plant) because of similarities in lifestyle: both fungi and plants are mainly [immobile](https://en.wikipedia.org/wiki/Sessility_(zoology)), and have similarities in general morphology and growth habitat. Like plants, fungi often grow in soil and, in the case of [mushrooms](https://en.wikipedia.org/wiki/Mushroom), form conspicuous [fruit bodies](https://en.wikipedia.org/wiki/Fruit_bodies), which sometimes resemble plants, such as [mosses](https://en.wikipedia.org/wiki/Mosses). The fungi are now considered a separate kingdom, distinct from both plants and animals, from which they appear to have [diverged](https://en.wikipedia.org/wiki/Genetic_divergence) around one billion years ago.[[10]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bruns2006-10)[[11]](https://en.wikipedia.org/wiki/Fungus#cite_note-Baldauf1993-11) Some morphological, biochemical, and genetic features are shared with other organisms, while others are unique to the fungi, clearly separating them from the other kingdoms:

Shared features:

* With other [eukaryotes](https://en.wikipedia.org/wiki/Eukaryote): Fungal cells contain [membrane-bound](https://en.wikipedia.org/wiki/Membrane-bound) [nuclei](https://en.wikipedia.org/wiki/Cell_nucleus) with [chromosomes](https://en.wikipedia.org/wiki/Chromosomes) that contain DNA with [noncoding regions](https://en.wikipedia.org/wiki/Noncoding_DNA" \o "Noncoding DNA) called [introns](https://en.wikipedia.org/wiki/Intron" \o "Intron) and coding regions called [exons](https://en.wikipedia.org/wiki/Exons" \o "Exons). Fungi have membrane-bound cytoplasmic [organelles](https://en.wikipedia.org/wiki/Organelles) such as[mitochondria](https://en.wikipedia.org/wiki/Mitochondria), [sterol](https://en.wikipedia.org/wiki/Sterol)-containing membranes, and [ribosomes](https://en.wikipedia.org/wiki/Ribosomes" \o "Ribosomes) of the [80S](https://en.wikipedia.org/wiki/80S) type.[[12]](https://en.wikipedia.org/wiki/Fungus#cite_note-12) They have a characteristic range of soluble carbohydrates and storage compounds, including [sugar alcohols](https://en.wikipedia.org/wiki/Sugar_alcohol) (e.g., [mannitol](https://en.wikipedia.org/wiki/Mannitol" \o "Mannitol)), [disaccharides](https://en.wikipedia.org/wiki/Disaccharide), (e.g., [trehalose](https://en.wikipedia.org/wiki/Trehalose" \o "Trehalose)), and [polysaccharides](https://en.wikipedia.org/wiki/Polysaccharide) (e.g., [glycogen](https://en.wikipedia.org/wiki/Glycogen), which is also found in animals[[13]](https://en.wikipedia.org/wiki/Fungus#cite_note-Deacon4-13)).
* With animals: Fungi lack [chloroplasts](https://en.wikipedia.org/wiki/Chloroplast) and are [heterotrophic](https://en.wikipedia.org/wiki/Heterotroph) organisms and so require preformed [organic compounds](https://en.wikipedia.org/wiki/Organic_compound) as energy sources.[[14]](https://en.wikipedia.org/wiki/Fungus#cite_note-14)
* With plants: Fungi have a cell wall[[15]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-15) and [vacuoles](https://en.wikipedia.org/wiki/Vacuole).[[16]](https://en.wikipedia.org/wiki/Fungus#cite_note-Shoji2006-16) They reproduce by both sexual and asexual means, and like [basal](https://en.wikipedia.org/wiki/Primitive_(phylogenetics)) plant groups (such as [ferns](https://en.wikipedia.org/wiki/Fern) and[mosses](https://en.wikipedia.org/wiki/Moss)) produce [spores](https://en.wikipedia.org/wiki/Spore). Similar to mosses and algae, fungi typically have [haploid](https://en.wikipedia.org/wiki/Haploid) nuclei.[[17]](https://en.wikipedia.org/wiki/Fungus#cite_note-Deacon58-17)
* With [euglenoids](https://en.wikipedia.org/wiki/Euglenoid" \o "Euglenoid) and bacteria: Higher fungi, euglenoids, and some bacteria produce the [amino acid](https://en.wikipedia.org/wiki/Amino_acid) L-lysine in specific [biosynthesis](https://en.wikipedia.org/wiki/Biosynthesis) steps, called the [α-aminoadipate pathway](https://en.wikipedia.org/wiki/%CE%91-aminoadipate_pathway).[[18]](https://en.wikipedia.org/wiki/Fungus#cite_note-Zabriskie2000-18)[[19]](https://en.wikipedia.org/wiki/Fungus#cite_note-Xu2006-19)
* The cells of most fungi grow as tubular, elongated, and thread-like (filamentous) structures called [hyphae](https://en.wikipedia.org/wiki/Hyphae" \o "Hyphae), which may contain multiple nuclei and extend by growing at their tips. Each tip contains a set of aggregated [vesicles](https://en.wikipedia.org/wiki/Vesicle_(biology))—cellular structures consisting of [proteins](https://en.wikipedia.org/wiki/Protein), [lipids](https://en.wikipedia.org/wiki/Lipid), and other organic molecules—called the[Spitzenkörper](https://en.wikipedia.org/wiki/Spitzenk%C3%B6rper).[[20]](https://en.wikipedia.org/wiki/Fungus#cite_note-20) Both fungi and [oomycetes](https://en.wikipedia.org/wiki/Oomycete" \o "Oomycete) grow as filamentous hyphal cells.[[21]](https://en.wikipedia.org/wiki/Fungus#cite_note-21) In contrast, similar-looking organisms, such as filamentous [green algae](https://en.wikipedia.org/wiki/Green_algae), grow by repeated cell division within a chain of cells.[[13]](https://en.wikipedia.org/wiki/Fungus#cite_note-Deacon4-13) There are also single-celled fungi ([yeasts](https://en.wikipedia.org/wiki/Yeast)) that do not form hyphae, and fungi with both hyphal and yeast forms.[[22]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alexopoulos_et_al..2C_p._30-22)
* In common with some plant and animal species, [more than 70 fungal species](https://en.wikipedia.org/wiki/List_of_bioluminescent_fungi) display [bioluminescence](https://en.wikipedia.org/wiki/Bioluminescence).[[23]](https://en.wikipedia.org/wiki/Fungus#cite_note-Desjardin_2010-23)

Unique features:

* Some species grow as unicellular yeasts that reproduce by [budding](https://en.wikipedia.org/wiki/Budding) or [binary fission](https://en.wikipedia.org/wiki/Binary_fission). [Dimorphic fungi](https://en.wikipedia.org/wiki/Dimorphic_fungi) can switch between a yeast phase and a hyphal phase in response to environmental conditions.[[22]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alexopoulos_et_al..2C_p._30-22)
* The fungal cell wall is composed of [glucans](https://en.wikipedia.org/wiki/Glucan" \o "Glucan) and [chitin](https://en.wikipedia.org/wiki/Chitin); while glucans are also found in plants and chitin in the [exoskeleton](https://en.wikipedia.org/wiki/Exoskeleton) of [arthropods](https://en.wikipedia.org/wiki/Arthropods),[[24]](https://en.wikipedia.org/wiki/Fungus#cite_note-24)[[25]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bowman2006-25) fungi are the only organisms that combine these two structural molecules in their cell wall. Unlike those of plants and oomycetes, fungal cell walls do not contain cellulose.

Most fungi lack an efficient system for the long-distance transport of water and nutrients, such as the [xylem](https://en.wikipedia.org/wiki/Xylem) and [phloem](https://en.wikipedia.org/wiki/Phloem) in many plants. To overcome this limitation, some fungi, such as *[Armillaria](https://en.wikipedia.org/wiki/Armillaria" \o "Armillaria)*, form [rhizomorphs](https://en.wikipedia.org/wiki/Mycelial_cord" \o "Mycelial cord),[[27]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-Mikhail2005-27) which resemble and perform functions similar to the [roots](https://en.wikipedia.org/wiki/Root) of plants. As eukaryotes, fungi possess a [biosynthetic pathway](https://en.wikipedia.org/wiki/Biochemical_pathway) for producing [terpenes](https://en.wikipedia.org/wiki/Terpene" \o "Terpene) that uses[mevalonic acid](https://en.wikipedia.org/wiki/Mevalonic_acid) and [pyrophosphate](https://en.wikipedia.org/wiki/Pyrophosphate) as [chemical building blocks](https://en.wikipedia.org/wiki/Precursor_(chemistry)).[[28]](https://en.wikipedia.org/wiki/Fungus#cite_note-Keller2005-28) Plants and some other organisms have an additional terpene biosynthesis pathway in their chloroplasts, a structure fungi and animals do not have.[[29]](https://en.wikipedia.org/wiki/Fungus#cite_note-Wu2007-29) Fungi produce several[secondary metabolites](https://en.wikipedia.org/wiki/Secondary_metabolite) that are similar or identical in structure to those made by plants.[[28]](https://en.wikipedia.org/wiki/Fungus#cite_note-Keller2005-28) Many of the plant and fungal enzymes that make these compounds differ from each other in [sequence](https://en.wikipedia.org/wiki/Peptide_sequence) and other characteristics, which indicates separate origins and evolution of these enzymes in the fungi and plants.[[28]](https://en.wikipedia.org/wiki/Fungus#cite_note-Keller2005-28)[[30]](https://en.wikipedia.org/wiki/Fungus#cite_note-Tudzynski2005-30)

## Diversity

Fungi have a worldwide distribution, and grow in a wide range of habitats, including extreme environments such as [deserts](https://en.wikipedia.org/wiki/Desert_fungi) or areas with high salt concentrations[[31]](https://en.wikipedia.org/wiki/Fungus#cite_note-Vaupotic2008-31) or [ionizing radiation](https://en.wikipedia.org/wiki/Ionizing_radiation),[[32]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dadachova2007-32) as well as in [deep sea](https://en.wikipedia.org/wiki/Deep_sea) sediments.[[33]](https://en.wikipedia.org/wiki/Fungus#cite_note-Raghukumar1998-33) Some can survive the intense [UV](https://en.wikipedia.org/wiki/Ultraviolet_radiation) and [cosmic radiation](https://en.wikipedia.org/wiki/Cosmic_radiation) encountered during space travel.[[34]](https://en.wikipedia.org/wiki/Fungus#cite_note-Sancho2007-34) Most grow in terrestrial environments, though several species live partly or solely in aquatic habitats, such as the [chytrid](https://en.wikipedia.org/wiki/Chytrid" \o "Chytrid) fungus *[Batrachochytrium dendrobatidis](https://en.wikipedia.org/wiki/Batrachochytrium_dendrobatidis" \o "Batrachochytrium dendrobatidis)*, a [parasite](https://en.wikipedia.org/wiki/Parasite) that has been responsible for a worldwide decline in [amphibian](https://en.wikipedia.org/wiki/Amphibian) populations. This organism spends part of its life cycle as a motile[zoospore](https://en.wikipedia.org/wiki/Zoospore), enabling it to propel itself through water and enter its amphibian host.[[35]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brem2008-35) Other examples of aquatic fungi include those living in [hydrothermal](https://en.wikipedia.org/wiki/Hydrothermal) areas of the ocean.[[36]](https://en.wikipedia.org/wiki/Fungus#cite_note-LeCalvez2009-36)

Around 100,000 species of fungi have been formally [described](https://en.wikipedia.org/wiki/Species_description) by [taxonomists](https://en.wikipedia.org/wiki/Taxonomy_(biology)),[[37]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-37) but the global biodiversity of the fungus kingdom is not fully understood.[[38]](https://en.wikipedia.org/wiki/Fungus#cite_note-Mueller2006-38) On the basis of observations of the ratio of the number of fungal species to the number of plant species in selected environments, the fungal kingdom has been estimated to contain about 1.5 million species.[[39]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hawksworth2006b-39) A recent (2011) estimate suggests there may be over 5 million species.[[40]](https://en.wikipedia.org/wiki/Fungus#cite_note-Blackwell2011-40) In mycology, species have historically been distinguished by a variety of methods and concepts. Classification based on [morphological](https://en.wikipedia.org/wiki/Morphology_(biology)) characteristics, such as the size and shape of spores or fruiting structures, has traditionally dominated fungal taxonomy.[[41]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kirk_et_al..2C_p._489-41) Species may also be distinguished by their [biochemical](https://en.wikipedia.org/wiki/Biochemistry) and [physiological](https://en.wikipedia.org/wiki/Physiology" \o "Physiology)characteristics, such as their ability to metabolize certain biochemicals, or their reaction to [chemical tests](https://en.wikipedia.org/wiki/Chemical_tests_in_mushroom_identification). The [biological species concept](https://en.wikipedia.org/wiki/Species#The_isolation_species_concept_in_more_detail) discriminates species based on their ability to [mate](https://en.wikipedia.org/wiki/Mating_in_fungi). The application of [molecular](https://en.wikipedia.org/wiki/Molecular_biology) tools, such as [DNA sequencing](https://en.wikipedia.org/wiki/DNA_sequencing) and phylogenetic analysis, to study diversity has greatly enhanced the resolution and added robustness to estimates of [genetic diversity](https://en.wikipedia.org/wiki/Genetic_diversity) within various taxonomic groups.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42)

[](https://en.wikipedia.org/wiki/File:Aa_black_and_white_fungi_2.jpg)

Two types of edible fungi

## Mycology

[Mycology](https://en.wikipedia.org/wiki/Mycology) is the branch of [biology](https://en.wikipedia.org/wiki/Biology) concerned with the systematic study of fungi, including their genetic and biochemical properties, their taxonomy, and their use to humans as a source of medicine, food, and [psychotropic substances](https://en.wikipedia.org/wiki/Entheogen) consumed for religious purposes, as well as their dangers, such as poisoning or infection. The field of [phytopathology](https://en.wikipedia.org/wiki/Phytopathology" \o "Phytopathology), the study of plant diseases, is closely related because many plant pathogens are fungi.[[43]](https://en.wikipedia.org/wiki/Fungus#cite_note-Struck2006-43)

[](https://en.wikipedia.org/wiki/File:Pier_Antonio_Micheli.jpg)

In 1729, Pier A. Micheli first published descriptions of fungi.

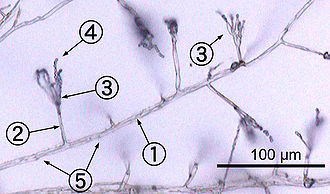
The use of fungi by humans dates back to prehistory; [Ötzi the Iceman](https://en.wikipedia.org/wiki/%C3%96tzi_the_Iceman" \o "Ötzi the Iceman), a well-preserved mummy of a 5,300-year-old [Neolithic](https://en.wikipedia.org/wiki/Neolithic) man found frozen in the Austrian Alps, carried two species of [polypore](https://en.wikipedia.org/wiki/Polypore" \o "Polypore)mushrooms that may have been used as [tinder](https://en.wikipedia.org/wiki/Tinder) (*[Fomes fomentarius](https://en.wikipedia.org/wiki/Fomes_fomentarius" \o "Fomes fomentarius)*), or for medicinal purposes (*[Piptoporus betulinus](https://en.wikipedia.org/wiki/Piptoporus_betulinus" \o "Piptoporus betulinus)*).[[44]](https://en.wikipedia.org/wiki/Fungus#cite_note-Peintner1998-44) Ancient peoples have used fungi as food sources–often unknowingly–for millennia, in the preparation of leavened bread and fermented juices. Some of the oldest written records contain references to the destruction of crops that were probably caused by pathogenic fungi.[[45]](https://en.wikipedia.org/wiki/Fungus#cite_note-45)

### History

Mycology is a relatively new science that became systematic after the development of the [microscope](https://en.wikipedia.org/wiki/Microscope) in the 16th century. Although fungal spores were first observed by [Giambattista della Porta](https://en.wikipedia.org/wiki/Giambattista_della_Porta" \o "Giambattista della Porta) in 1588, the seminal work in the development of mycology is considered to be the publication of [Pier Antonio Micheli](https://en.wikipedia.org/wiki/Pier_Antonio_Micheli)'s 1729 work *Nova plantarum genera*.[[46]](https://en.wikipedia.org/wiki/Fungus#cite_note-46) Micheli not only observed spores but also showed that, under the proper conditions, they could be induced into growing into the same species of fungi from which they originated.[[47]](https://en.wikipedia.org/wiki/Fungus#cite_note-47) Extending the use of the [binomial system of nomenclature](https://en.wikipedia.org/wiki/Binomial_nomenclature) introduced by [Carl Linnaeus](https://en.wikipedia.org/wiki/Carl_Linnaeus) in his [*Species plantarum*](https://en.wikipedia.org/wiki/Species_plantarum) (1753), the Dutch [Christian Hendrik Persoon](https://en.wikipedia.org/wiki/Christian_Hendrik_Persoon) (1761–1836) established the first classification of mushrooms with such skill so as to be considered a founder of modern mycology. Later, [Elias Magnus Fries](https://en.wikipedia.org/wiki/Elias_Magnus_Fries) (1794–1878) further elaborated the [classification](https://en.wikipedia.org/wiki/Biological_classification) of fungi, using spore color and various microscopic characteristics, methods still used by taxonomists today. Other notable early contributors to mycology in the 17th–19th and early 20th centuries include [Miles Joseph Berkeley](https://en.wikipedia.org/wiki/Miles_Joseph_Berkeley), [August Carl Joseph Corda](https://en.wikipedia.org/wiki/August_Carl_Joseph_Corda), [Anton de Bary](https://en.wikipedia.org/wiki/Anton_de_Bary), the brothers [Louis René](https://en.wikipedia.org/wiki/Louis_Ren%C3%A9_Tulasne) and [Charles Tulasne](https://en.wikipedia.org/wiki/Charles_Tulasne), [Arthur H. R. Buller](https://en.wikipedia.org/wiki/Arthur_Henry_Reginald_Buller), [Curtis G. Lloyd](https://en.wikipedia.org/wiki/Curtis_Gates_Lloyd), and [Pier Andrea Saccardo](https://en.wikipedia.org/wiki/Pier_Andrea_Saccardo). The 20th century has seen a modernization of mycology that has come from advances in [biochemistry](https://en.wikipedia.org/wiki/Biochemistry), [genetics](https://en.wikipedia.org/wiki/Genetics), [molecular biology](https://en.wikipedia.org/wiki/Molecular_biology), and [biotechnology](https://en.wikipedia.org/wiki/Biotechnology). The use of [DNA sequencing](https://en.wikipedia.org/wiki/DNA_sequencing)technologies and phylogenetic analysis has provided new insights into fungal relationships and [biodiversity](https://en.wikipedia.org/wiki/Biodiversity), and has challenged traditional morphology-based groupings in fungal [taxonomy](https://en.wikipedia.org/wiki/Taxonomy_(biology)).[[48]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hawksworth2006-48)

## Morphology

### Microscopic structures

[](https://en.wikipedia.org/wiki/File:Penicillium_labeled_cropped.jpg)

An environmental isolate of *[Penicillium](https://en.wikipedia.org/wiki/Penicillium" \o "Penicillium)*

1. [hypha](https://en.wikipedia.org/wiki/Hypha)
2. [conidiophore](https://en.wikipedia.org/wiki/Conidiophore)
3. [phialide](https://en.wikipedia.org/wiki/Phialide)
4. [conidia](https://en.wikipedia.org/wiki/Conidia)
5. [septa](https://en.wikipedia.org/wiki/Septum)

Most fungi grow as [hyphae](https://en.wikipedia.org/wiki/Hypha" \o "Hypha), which are cylindrical, thread-like structures 2–10 [µm](https://en.wikipedia.org/wiki/Micrometres) in diameter and up to several centimeters in length. Hyphae grow at their tips (apices); new hyphae are typically formed by emergence of new tips along existing hyphae by a process called *branching*, or occasionally growing hyphal tips fork, giving rise to two parallel-growing hyphae.[[49]](https://en.wikipedia.org/wiki/Fungus#cite_note-Harris2008-49) The combination of apical growth and branching/forking leads to the development of a [mycelium](https://en.wikipedia.org/wiki/Mycelium), an interconnected network of hyphae.[[22]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alexopoulos_et_al..2C_p._30-22)Hyphae can be either [septate](https://en.wikipedia.org/wiki/Septum" \o "Septum) or [coenocytic](https://en.wikipedia.org/wiki/Coenocytic" \o "Coenocytic). Septate hyphae are divided into compartments separated by cross walls (internal cell walls, called septa, that are formed at [right angles](https://en.wikipedia.org/wiki/Right_angle) to the cell wall giving the hypha its shape), with each compartment containing one or more nuclei; coenocytic hyphae are not compartmentalized.[[50]](https://en.wikipedia.org/wiki/Fungus#cite_note-50) Septa have [pores](https://en.wikipedia.org/wiki/Pit_connection#Characteristics) that allow [cytoplasm](https://en.wikipedia.org/wiki/Cytoplasm), [organelles](https://en.wikipedia.org/wiki/Organelle), and sometimes nuclei to pass through; an example is the dolipore septum in fungi of the phylum Basidiomycota.[[51]](https://en.wikipedia.org/wiki/Fungus#cite_note-51) Coenocytic hyphae are in essence [multinucleate](https://en.wikipedia.org/wiki/Multinucleate) supercells.[[52]](https://en.wikipedia.org/wiki/Fungus#cite_note-Chang2004-52)

Many species have developed specialized hyphal structures for nutrient uptake from living hosts; examples include [haustoria](https://en.wikipedia.org/wiki/Haustoria" \o "Haustoria) in plant-parasitic species of most fungal phyla, and [arbuscules](https://en.wikipedia.org/wiki/Arbuscular_mycorrhiza" \o "Arbuscular mycorrhiza) of several [mycorrhizal](https://en.wikipedia.org/wiki/Mycorrhiza" \o "Mycorrhiza) fungi, which penetrate into the host cells to consume nutrients.[[53]](https://en.wikipedia.org/wiki/Fungus#cite_note-Parniske2008-53)

Although fungi are [opisthokonts](https://en.wikipedia.org/wiki/Opisthokont" \o "Opisthokont)—a grouping of evolutionarily related organisms broadly characterized by a single posterior [flagellum](https://en.wikipedia.org/wiki/Flagellum)—all phyla except for the[chytrids](https://en.wikipedia.org/wiki/Chytrids) have lost their posterior flagella.[[54]](https://en.wikipedia.org/wiki/Fungus#cite_note-Steenkamp2006-54) Fungi are unusual among the eukaryotes in having a cell wall that, in addition to [glucans](https://en.wikipedia.org/wiki/Glucan" \o "Glucan) (e.g., β-1,3-glucan) and other typical components, also contains the [biopolymer](https://en.wikipedia.org/wiki/Biopolymer) chitin.[[55]](https://en.wikipedia.org/wiki/Fungus#cite_note-Stevens2006-55)

### Macroscopic structures

[](https://en.wikipedia.org/wiki/File:Armillaria_ostoyae_MO.jpg)

[*Armillaria solidipes*](https://en.wikipedia.org/wiki/Armillaria_solidipes)

Fungal mycelia can become visible to the naked eye, for example, on various surfaces and [substrates](https://en.wikipedia.org/wiki/Substrate_(biology)), such as damp walls and spoiled food, where they are commonly called [molds](https://en.wikipedia.org/wiki/Mold). Mycelia grown on solid [agar](https://en.wikipedia.org/wiki/Agar) media in laboratory [petri dishes](https://en.wikipedia.org/wiki/Petri_dish" \o "Petri dish) are usually referred to as [colonies](https://en.wikipedia.org/wiki/Colony_(biology)). These colonies can exhibit growth shapes and colors (due to spores or [pigmentation](https://en.wikipedia.org/wiki/Biological_pigment)) that can be used as diagnostic features in the identification of species or groups.[[56]](https://en.wikipedia.org/wiki/Fungus#cite_note-56) Some individual fungal colonies can reach extraordinary dimensions and ages as in the case of a [clonal](https://en.wikipedia.org/wiki/Clone_(cell_biology)" \o "Clone (cell biology)) colony of *[Armillaria solidipes](https://en.wikipedia.org/wiki/Armillaria_solidipes" \o "Armillaria solidipes)*, which extends over an area of more than 900 [ha](https://en.wikipedia.org/wiki/Hectare) (3.5 square miles), with an estimated age of nearly 9,000 years.[[57]](https://en.wikipedia.org/wiki/Fungus#cite_note-Ferguson2003-57)

The [apothecium](https://en.wikipedia.org/wiki/Apothecium" \o "Apothecium)—a specialized structure important in [sexual reproduction](https://en.wikipedia.org/wiki/Sexual_reproduction) in the ascomycetes—is a cup-shaped fruit body that holds the [hymenium](https://en.wikipedia.org/wiki/Hymenium" \o "Hymenium), a layer of tissue containing the spore-bearing cells.[[58]](https://en.wikipedia.org/wiki/Fungus#cite_note-58) The fruit bodies of the basidiomycetes ([basidiocarps](https://en.wikipedia.org/wiki/Basidiocarp" \o "Basidiocarp)) and some ascomycetes can sometimes grow very large, and many are well known as [mushrooms](https://en.wikipedia.org/wiki/Mushroom).

## Growth and physiology

[](https://en.wikipedia.org/wiki/File:DecayingPeachSmall.gif)

[Mold](https://en.wikipedia.org/wiki/Mold) growth covering a decaying[peach](https://en.wikipedia.org/wiki/Peach). The frames were taken approximately 12 hours apart over a period of six days.

The growth of fungi as hyphae on or in solid substrates or as single cells in aquatic environments is adapted for the efficient extraction of nutrients, because these growth forms have high [surface area to volume ratios](https://en.wikipedia.org/wiki/Surface_area_to_volume_ratio).[[59]](https://en.wikipedia.org/wiki/Fungus#cite_note-Moss1986-59) Hyphae are specifically adapted for growth on solid surfaces, and to invade [substrates](https://en.wikipedia.org/wiki/Substrate_(biology)) and tissues.[[60]](https://en.wikipedia.org/wiki/Fungus#cite_note-Penalva2002-60) They can exert large penetrative mechanical forces; for example, the [plant pathogen](https://en.wikipedia.org/wiki/Plant_pathogen) *[Magnaporthe grisea](https://en.wikipedia.org/wiki/Magnaporthe_grisea" \o "Magnaporthe grisea)* forms a structure called an [appressorium](https://en.wikipedia.org/wiki/Appressorium" \o "Appressorium) that evolved to puncture plant tissues.[[61]](https://en.wikipedia.org/wiki/Fungus#cite_note-Howard1991-61) The pressure generated by the appressorium, directed against the plant [epidermis](https://en.wikipedia.org/wiki/Epidermis_(botany)), can exceed 8 [megapascals](https://en.wikipedia.org/wiki/Pascal_(unit)" \o "Pascal (unit))(1,200 psi).[[61]](https://en.wikipedia.org/wiki/Fungus#cite_note-Howard1991-61) The filamentous fungus *[Paecilomyces lilacinus](https://en.wikipedia.org/wiki/Paecilomyces_lilacinus" \o "Paecilomyces lilacinus)* uses a similar structure to penetrate the eggs of [nematodes](https://en.wikipedia.org/wiki/Nematode).[[62]](https://en.wikipedia.org/wiki/Fungus#cite_note-Money1997-62)

The mechanical pressure exerted by the appressorium is generated from physiological processes that increase intracellular[turgor](https://en.wikipedia.org/wiki/Turgor) by producing [osmolytes](https://en.wikipedia.org/wiki/Osmolyte" \o "Osmolyte) such as [glycerol](https://en.wikipedia.org/wiki/Glycerol).[[63]](https://en.wikipedia.org/wiki/Fungus#cite_note-Wang2005-63) Adaptations such as these are complemented by [hydrolytic enzymes](https://en.wikipedia.org/wiki/Cellulase)secreted into the environment to digest large organic molecules—such as [polysaccharides](https://en.wikipedia.org/wiki/Polysaccharide), [proteins](https://en.wikipedia.org/wiki/Protein), and [lipids](https://en.wikipedia.org/wiki/Lipid)—into smaller molecules that may then be absorbed as nutrients.[[64]](https://en.wikipedia.org/wiki/Fungus#cite_note-Pereira2007-64)[[65]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schaller2007-65)[[66]](https://en.wikipedia.org/wiki/Fungus#cite_note-Farrar1985-66) The vast majority of filamentous fungi grow in a polar fashion—i.e., by extension into one direction—by elongation at the tip (apex) of the hypha.[[67]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fischer2008-67) Other forms of fungal growth include intercalary extension (longitudinal expansion of hyphal compartments that are below the apex) as in the case of some [endophytic](https://en.wikipedia.org/wiki/Endophyte" \o "Endophyte) fungi,[[68]](https://en.wikipedia.org/wiki/Fungus#cite_note-Christensen2008-68)or growth by volume expansion during the development of mushroom [stipes](https://en.wikipedia.org/wiki/Stipe_(mycology)" \o "Stipe (mycology)) and other large organs.[[69]](https://en.wikipedia.org/wiki/Fungus#cite_note-Money2002-69) Growth of fungi as[multicellular structures](https://en.wikipedia.org/wiki/Multicellularity) consisting of [somatic](https://en.wikipedia.org/wiki/Somatic_(biology)) and reproductive cells—a feature independently evolved in animals and plants[[70]](https://en.wikipedia.org/wiki/Fungus#cite_note-Willensdorfer2009-70)—has several functions, including the development of fruit bodies for dissemination of sexual spores (see above) and [biofilms](https://en.wikipedia.org/wiki/Biofilm" \o "Biofilm) for substrate colonization and[intercellular communication](https://en.wikipedia.org/wiki/Intercellular_communication).[[71]](https://en.wikipedia.org/wiki/Fungus#cite_note-Daniels2006-71)

The fungi are traditionally considered [heterotrophs](https://en.wikipedia.org/wiki/Heterotroph" \o "Heterotroph), organisms that rely solely on [carbon fixed](https://en.wikipedia.org/wiki/Carbon_fixation) by other organisms for [metabolism](https://en.wikipedia.org/wiki/Metabolism). Fungi have [evolved](https://en.wikipedia.org/wiki/Evolution) a high degree of metabolic versatility that allows them to use a diverse range of organic substrates for growth, including simple compounds such as [nitrate](https://en.wikipedia.org/wiki/Nitrate), [ammonia](https://en.wikipedia.org/wiki/Ammonia), [acetate](https://en.wikipedia.org/wiki/Acetate), or[ethanol](https://en.wikipedia.org/wiki/Ethanol).[[72]](https://en.wikipedia.org/wiki/Fungus#cite_note-Marzluf1981-72)[[73]](https://en.wikipedia.org/wiki/Fungus#cite_note-Heynes1994-73) In some species the pigment [melanin](https://en.wikipedia.org/wiki/Melanin) may play a role in extracting energy from [ionizing radiation](https://en.wikipedia.org/wiki/Ionizing_radiation), such as [gamma radiation](https://en.wikipedia.org/wiki/Gamma_rays). This form of ["radiotrophic"](https://en.wikipedia.org/wiki/Radiotrophic_fungus)growth has been described for only a few species, the effects on growth rates are small, and the underlying [biophysical](https://en.wikipedia.org/wiki/Biophysics) and biochemical processes are not well known.[[32]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dadachova2007-32) This process might bear similarity to [CO2 fixation](https://en.wikipedia.org/wiki/Carbon_fixation) via [visible light](https://en.wikipedia.org/wiki/Visible_spectrum), but instead uses ionizing radiation as a source of energy.[[74]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dadachova2008-74)

## Reproduction

[](https://en.wikipedia.org/wiki/File:Polyporus_squamosus_Molter.jpg)

[*Polyporus squamosus*](https://en.wikipedia.org/wiki/Polyporus_squamosus)

Fungal reproduction is complex, reflecting the differences in lifestyles and genetic makeup within this diverse kingdom of organisms.[[75]](https://en.wikipedia.org/wiki/Fungus#cite_note-75) It is estimated that a third of all fungi reproduce using more than one method of propagation; for example, reproduction may occur in two well-differentiated stages within the [life cycle](https://en.wikipedia.org/wiki/Biological_life_cycle) of a species, the [teleomorph](https://en.wikipedia.org/wiki/Teleomorph" \o "Teleomorph) and the[anamorph](https://en.wikipedia.org/wiki/Anamorph).[[76]](https://en.wikipedia.org/wiki/Fungus#cite_note-76) Environmental conditions trigger genetically determined developmental states that lead to the creation of specialized structures for sexual or asexual reproduction. These structures aid reproduction by efficiently dispersing spores or spore-containing [propagules](https://en.wikipedia.org/wiki/Propagule" \o "Propagule).

### Asexual reproduction

[Asexual reproduction](https://en.wikipedia.org/wiki/Asexual_reproduction) occurs via vegetative spores ([conidia](https://en.wikipedia.org/wiki/Conidium)) or through [mycelial fragmentation](https://en.wikipedia.org/w/index.php?title=Mycelial_fragmentation&action=edit&redlink=1" \o "Mycelial fragmentation (page does not exist)). Mycelial fragmentation occurs when a fungal mycelium separates into pieces, and each component grows into a separate mycelium. Mycelial fragmentation and vegatative spores maintain [clonal](https://en.wikipedia.org/wiki/Clone_(genetics)" \o "Clone (genetics)) populations adapted to a specific [niche](https://en.wikipedia.org/wiki/Ecological_niche), and allow more rapid dispersal than sexual reproduction.[[77]](https://en.wikipedia.org/wiki/Fungus#cite_note-Heitman2005-77) The "Fungi imperfecti" (fungi lacking the perfect or sexual stage) or [Deuteromycota](https://en.wikipedia.org/wiki/Deuteromycota" \o "Deuteromycota) comprise all the species that lack an observable sexual cycle.[[78]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alcamo2004-78)

### Sexual reproduction

*See also:*[*Mating in fungi*](https://en.wikipedia.org/wiki/Mating_in_fungi)

Sexual reproduction with [meiosis](https://en.wikipedia.org/wiki/Meiosis) exists in all fungal phyla except [Glomeromycota](https://en.wikipedia.org/wiki/Glomeromycota" \o "Glomeromycota).[[79]](https://en.wikipedia.org/wiki/Fungus#cite_note-Redecker2006-79) It differs in many aspects from sexual reproduction in animals or plants. Differences also exist between fungal groups and can be used to discriminate species by morphological differences in sexual structures and reproductive strategies.[[80]](https://en.wikipedia.org/wiki/Fungus#cite_note-Guarro1999-80)[[81]](https://en.wikipedia.org/wiki/Fungus#cite_note-Taylor2000-81) Mating experiments between fungal isolates may identify species on the basis of biological species concepts.[[81]](https://en.wikipedia.org/wiki/Fungus#cite_note-Taylor2000-81) The major fungal groupings have initially been delineated based on the morphology of their sexual structures and spores; for example, the spore-containing structures, [asci](https://en.wikipedia.org/wiki/Ascus" \o "Ascus) and [basidia](https://en.wikipedia.org/wiki/Basidium" \o "Basidium), can be used in the identification of ascomycetes and basidiomycetes, respectively. Some species may allow mating only between individuals of opposite [mating type](https://en.wikipedia.org/wiki/Mating_type), whereas others can mate and sexually reproduce with any other individual or itself. Species of the former [mating system](https://en.wikipedia.org/wiki/Mating_system) are called [heterothallic](https://en.wikipedia.org/wiki/Heterothallic), and of the latter[homothallic](https://en.wikipedia.org/wiki/Homothallic).[[82]](https://en.wikipedia.org/wiki/Fungus#cite_note-Metzenberg1990-82)

Most fungi have both a [haploid](https://en.wikipedia.org/wiki/Haploid) and a [diploid](https://en.wikipedia.org/wiki/Diploid) stage in their life cycles. In sexually reproducing fungi, compatible individuals may combine by fusing their hyphae together into an interconnected network; this process, [anastomosis](https://en.wikipedia.org/wiki/Anastomosis" \o "Anastomosis), is required for the initiation of the sexual cycle. Ascomycetes and basidiomycetes go through a[dikaryotic](https://en.wikipedia.org/wiki/Dikaryotic) stage, in which the nuclei inherited from the two parents do not combine immediately after cell fusion, but remain separate in the hyphal cells (see[heterokaryosis](https://en.wikipedia.org/wiki/Heterokaryosis)).[[83]](https://en.wikipedia.org/wiki/Fungus#cite_note-83)

[](https://en.wikipedia.org/wiki/File:Morelasci.jpg)

The 8-spore asci of *[Morchella elata](https://en.wikipedia.org/wiki/Morchella_elata" \o "Morchella elata)*, viewed with [phase contrast microscopy](https://en.wikipedia.org/wiki/Phase_contrast_microscopy)

In ascomycetes, dikaryotic hyphae of the [hymenium](https://en.wikipedia.org/wiki/Hymenium" \o "Hymenium) (the spore-bearing tissue layer) form a characteristic *hook* at the hyphal septum. During [cell division](https://en.wikipedia.org/wiki/Cell_division), formation of the hook ensures proper distribution of the newly divided nuclei into the apical and basal hyphal compartments. An ascus (plural *asci*) is then formed, in which [karyogamy](https://en.wikipedia.org/wiki/Karyogamy" \o "Karyogamy) (nuclear fusion) occurs. Asci are embedded in an [ascocarp](https://en.wikipedia.org/wiki/Ascocarp" \o "Ascocarp), or fruiting body. Karyogamy in the asci is followed immediately by meiosis and the production of[ascospores](https://en.wikipedia.org/wiki/Ascospore). After dispersal, the ascospores may germinate and form a new haploid mycelium.[[84]](https://en.wikipedia.org/wiki/Fungus#cite_note-84)

Sexual reproduction in basidiomycetes is similar to that of the ascomycetes. Compatible haploid hyphae fuse to produce a dikaryotic mycelium. However, the dikaryotic phase is more extensive in the basidiomycetes, often also present in the vegetatively growing mycelium. A specialized anatomical structure, called a [clamp connection](https://en.wikipedia.org/wiki/Clamp_connection), is formed at each hyphal septum. As with the structurally similar hook in the ascomycetes, the clamp connection in the basidiomycetes is required for controlled transfer of nuclei during cell division, to maintain the dikaryotic stage with two genetically different nuclei in each hyphal compartment.[[85]](https://en.wikipedia.org/wiki/Fungus#cite_note-85) A [basidiocarp](https://en.wikipedia.org/wiki/Basidiocarp" \o "Basidiocarp) is formed in which club-like structures known as [basidia](https://en.wikipedia.org/wiki/Basidia" \o "Basidia) generate haploid[basidiospores](https://en.wikipedia.org/wiki/Basidiospores) after karyogamy and meiosis.[[86]](https://en.wikipedia.org/wiki/Fungus#cite_note-86) The most commonly known basidiocarps are mushrooms, but they may also take other forms (see [Morphology](https://en.wikipedia.org/wiki/Fungus" \l "Morphology" \o "Fungus)section).

In glomeromycetes (formerly zygomycetes), haploid hyphae of two individuals fuse, forming a [gametangium](https://en.wikipedia.org/wiki/Gametangium" \o "Gametangium), a specialized cell structure that becomes a fertile[gamete](https://en.wikipedia.org/wiki/Gamete)-producing cell. The gametangium develops into a [zygospore](https://en.wikipedia.org/wiki/Zygospore" \o "Zygospore), a thick-walled spore formed by the union of gametes. When the zygospore germinates, it undergoes [meiosis](https://en.wikipedia.org/wiki/Meiosis), generating new haploid hyphae, which may then form asexual [sporangiospores](https://en.wikipedia.org/wiki/Sporangiospore" \o "Sporangiospore). These sporangiospores allow the fungus to rapidly disperse and germinate into new genetically identical haploid fungal mycelia.[[87]](https://en.wikipedia.org/wiki/Fungus#cite_note-87)

### Spore dispersal

Both asexual and sexual spores or sporangiospores are often actively dispersed by forcible ejection from their reproductive structures. This ejection ensures exit of the spores from the reproductive structures as well as traveling through the air over long distances.

[](https://en.wikipedia.org/wiki/File:Cyathus_stercoreus_Fruchtk%C3%B6rper.JPG)

The bird's nest fungus *[Cyathus stercoreus](https://en.wikipedia.org/wiki/Cyathus_stercoreus" \o "Cyathus stercoreus)*

Specialized mechanical and physiological mechanisms, as well as spore surface structures (such as [hydrophobins](https://en.wikipedia.org/wiki/Hydrophobin" \o "Hydrophobin)), enable efficient spore ejection.[[88]](https://en.wikipedia.org/wiki/Fungus#cite_note-Linder2005-88) For example, the structure of the [spore-bearing cells](https://en.wikipedia.org/wiki/Ascus) in some ascomycete species is such that the buildup of [substances](https://en.wikipedia.org/wiki/Osmolyte) affecting cell volume and fluid balance enables the explosive discharge of spores into the air.[[89]](https://en.wikipedia.org/wiki/Fungus#cite_note-Trail2007-89) The forcible discharge of single spores termed *ballistospores* involves formation of a small drop of water (Buller's drop), which upon contact with the spore leads to its projectile release with an initial acceleration of more than 10,000 [g](https://en.wikipedia.org/wiki/G-force);[[90]](https://en.wikipedia.org/wiki/Fungus#cite_note-Pringle2005-90) the net result is that the spore is ejected 0.01–0.02 cm, sufficient distance for it to fall through the gills or pores into the air below.[[91]](https://en.wikipedia.org/wiki/Fungus#cite_note-91) Other fungi, like the [puffballs](https://en.wikipedia.org/wiki/Puffballs), rely on alternative mechanisms for spore release, such as external mechanical forces. The [bird's nest fungi](https://en.wikipedia.org/wiki/Nidulariaceae) use the force of falling water drops to liberate the spores from cup-shaped fruiting bodies.[[92]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brodie1975-92) Another strategy is seen in the [stinkhorns](https://en.wikipedia.org/wiki/Stinkhorns), a group of fungi with lively colors and putrid odor that attract insects to disperse their spores.[[93]](https://en.wikipedia.org/wiki/Fungus#cite_note-93)

### Other sexual processes

Besides regular sexual reproduction with meiosis, certain fungi, such as those in the genera *[Penicillium](https://en.wikipedia.org/wiki/Penicillium" \o "Penicillium)* and *[Aspergillus](https://en.wikipedia.org/wiki/Aspergillus" \o "Aspergillus)*, may exchange genetic material via[parasexual](https://en.wikipedia.org/wiki/Parasexuality) processes, initiated by anastomosis between hyphae and [plasmogamy](https://en.wikipedia.org/wiki/Plasmogamy" \o "Plasmogamy) of fungal cells.[[94]](https://en.wikipedia.org/wiki/Fungus#cite_note-94) The frequency and relative importance of parasexual events is unclear and may be lower than other sexual processes. It is known to play a role in intraspecific hybridization[[95]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-Furlaneto1992-95) and is likely required for hybridization between species, which has been associated with major events in fungal evolution.[[96]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schardl2003-96)

## Evolution

*Main article:*[*Evolution of fungi*](https://en.wikipedia.org/wiki/Evolution_of_fungi)

In contrast to [plants](https://en.wikipedia.org/wiki/Evolutionary_history_of_plants) and [animals](https://en.wikipedia.org/wiki/Evolutionary_history_of_life), the early fossil record of the fungi is meager. Factors that likely contribute to the under-representation of fungal species among fossils include the nature of fungal [fruiting bodies](https://en.wikipedia.org/wiki/Sporocarp_(fungi)), which are soft, fleshy, and easily degradable tissues and the microscopic dimensions of most fungal structures, which therefore are not readily evident. Fungal fossils are difficult to distinguish from those of other microbes, and are most easily identified when they resemble[extant](https://en.wikipedia.org/wiki/Extant_taxon) fungi.[[97]](https://en.wikipedia.org/wiki/Fungus#cite_note-Donoghue2004-97) Often recovered from a [permineralized](https://en.wikipedia.org/wiki/Permineralization" \o "Permineralization) plant or animal host, these samples are typically studied by making thin-section preparations that can be examined with [light microscopy](https://en.wikipedia.org/wiki/Optical_microscope) or [transmission electron microscopy](https://en.wikipedia.org/wiki/Transmission_electron_microscopy).[[98]](https://en.wikipedia.org/wiki/Fungus#cite_note-98) Researchers study [compression fossils](https://en.wikipedia.org/wiki/Compression_fossil) by dissolving the surrounding matrix with acid and then using light or [scanning electron microscopy](https://en.wikipedia.org/wiki/Scanning_electron_microscopy) to examine surface details.[[99]](https://en.wikipedia.org/wiki/Fungus#cite_note-99)

The earliest fossils possessing features typical of fungi date to the [Proterozoic](https://en.wikipedia.org/wiki/Proterozoic" \o "Proterozoic) eon, some [1,430](http://tools.wmflabs.org/timescale/?Ma=1,430) [million years ago](https://en.wikipedia.org/wiki/Myr) ([Ma](https://en.wikipedia.org/wiki/Annum)); these multicellular [benthic](https://en.wikipedia.org/wiki/Benthic) organisms had filamentous structures with septa, and were capable of [anastomosis](https://en.wikipedia.org/wiki/Anastomosis" \o "Anastomosis).[[100]](https://en.wikipedia.org/wiki/Fungus#cite_note-Butterfield2005-100) More recent studies (2009) estimate the arrival of fungal organisms at about 760–1060 Ma on the basis of comparisons of the rate of evolution in closely related groups.[[101]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lucking2009-101) For much of the [Paleozoic](https://en.wikipedia.org/wiki/Paleozoic) Era (542–251 Ma), the fungi appear to have been aquatic and consisted of organisms similar to the extant [chytrids](https://en.wikipedia.org/wiki/Chytrid" \o "Chytrid) in having flagellum-bearing spores.[[102]](https://en.wikipedia.org/wiki/Fungus#cite_note-James2006b-102) The evolutionary adaptation from an aquatic to a terrestrial lifestyle necessitated a diversification of ecological strategies for obtaining nutrients, including [parasitism](https://en.wikipedia.org/wiki/Parasitism), [saprobism](https://en.wikipedia.org/wiki/Saphrotrophic_nutrition" \o "Saphrotrophic nutrition), and the development of [mutualistic](https://en.wikipedia.org/wiki/Mutualism_(biology)" \o "Mutualism (biology))relationships such as [mycorrhiza](https://en.wikipedia.org/wiki/Mycorrhiza" \o "Mycorrhiza) and lichenization.[[103]](https://en.wikipedia.org/wiki/Fungus#cite_note-103) Recent (2009) studies suggest that the ancestral ecological state of the [Ascomycota](https://en.wikipedia.org/wiki/Ascomycota" \o "Ascomycota) was saprobism, and that independent [lichenization](https://en.wikipedia.org/wiki/Lichen" \o "Lichen) events have occurred multiple times.[[104]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schoch2009-104)

It is presumed that the fungi colonized the land during the [Cambrian](https://en.wikipedia.org/wiki/Cambrian) (542–488.3 Ma), long before land plants.[[105]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brundrett2002-105) Fossilized hyphae and spores recovered from the[Ordovician](https://en.wikipedia.org/wiki/Ordovician) of Wisconsin (460 Ma) resemble modern-day [Glomerales](https://en.wikipedia.org/wiki/Glomerales" \o "Glomerales), and existed at a time when the land flora likely consisted of only non-vascular [bryophyte](https://en.wikipedia.org/wiki/Bryophyte)-like plants.[[106]](https://en.wikipedia.org/wiki/Fungus#cite_note-Redecker2000-106) [Prototaxites](https://en.wikipedia.org/wiki/Prototaxites" \o "Prototaxites), which was probably a fungus or lichen, would have been the tallest organism of the late [Silurian](https://en.wikipedia.org/wiki/Silurian). Fungal fossils do not become common and uncontroversial until the early [Devonian](https://en.wikipedia.org/wiki/Devonian) (416–359.2 Ma), when they occur abundantly in the [Rhynie chert](https://en.wikipedia.org/wiki/Rhynie_chert" \o "Rhynie chert), mostly as [Zygomycota](https://en.wikipedia.org/wiki/Zygomycota" \o "Zygomycota) and [Chytridiomycota](https://en.wikipedia.org/wiki/Chytridiomycota" \o "Chytridiomycota).[[105]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brundrett2002-105)[[107]](https://en.wikipedia.org/wiki/Fungus#cite_note-Taylor1996-107)[[108]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dotzler2009-108) At about this same time, approximately 400 Ma, the Ascomycota and Basidiomycota diverged,[[109]](https://en.wikipedia.org/wiki/Fungus#cite_note-Taylor2006-109) and all modern [classes](https://en.wikipedia.org/wiki/Class_(biology)) of fungi were present by the Late[Carboniferous](https://en.wikipedia.org/wiki/Carboniferous) ([Pennsylvanian](https://en.wikipedia.org/wiki/Pennsylvanian_(geology)), 318.1–299 Ma).[[110]](https://en.wikipedia.org/wiki/Fungus#cite_note-urlFungi-110)

[Lichen](https://en.wikipedia.org/wiki/Lichen)-like fossils have been found in the [Doushantuo Formation](https://en.wikipedia.org/wiki/Doushantuo_Formation" \o "Doushantuo Formation) in southern China dating back to 635–551 Ma.[[111]](https://en.wikipedia.org/wiki/Fungus#cite_note-Yuan2005-111) Lichens formed a component of the early terrestrial ecosystems, and the estimated age of the oldest terrestrial lichen fossil is 400 Ma;[[112]](https://en.wikipedia.org/wiki/Fungus#cite_note-Karatygin2009-112) this date corresponds to the age of the oldest known [sporocarp](https://en.wikipedia.org/wiki/Sporocarp_(fungi)" \o "Sporocarp (fungi))fossil, a *Paleopyrenomycites* species found in the Rhynie Chert.[[113]](https://en.wikipedia.org/wiki/Fungus#cite_note-Taylor2005-113) The oldest fossil with microscopic features resembling modern-day basidiomycetes is*Palaeoancistrus*, found permineralized with a [fern](https://en.wikipedia.org/wiki/Fern) from the Pennsylvanian.[[114]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dennis1970-114) Rare in the fossil record are the Homobasidiomycetes (a [taxon](https://en.wikipedia.org/wiki/Taxon" \o "Taxon) roughly equivalent to the mushroom-producing species of the [Agaricomycetes](https://en.wikipedia.org/wiki/Agaricomycetes" \o "Agaricomycetes)). Two [amber](https://en.wikipedia.org/wiki/Amber)-preserved specimens provide evidence that the earliest known mushroom-forming fungi (the extinct species *[Archaeomarasmius leggetti](https://en.wikipedia.org/wiki/Archaeomarasmius_leggetti" \o "Archaeomarasmius leggetti)*) appeared during the late [Cretaceous](https://en.wikipedia.org/wiki/Cretaceous), 90 Ma.[[115]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett1995-115)[[116]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett1997-116)

Some time after the [Permian–Triassic extinction event](https://en.wikipedia.org/wiki/Permian%E2%80%93Triassic_extinction_event) (251.4 Ma), a fungal spike (originally thought to be an extraordinary abundance of fungal spores in [sediments](https://en.wikipedia.org/wiki/Sediment)) formed, suggesting that fungi were the dominant life form at this time, representing nearly 100% of the available [fossil record](https://en.wikipedia.org/wiki/Fossil_record) for this period.[[117]](https://en.wikipedia.org/wiki/Fungus#cite_note-Eshet1995-117) However, the relative proportion of fungal spores relative to spores formed by [algal](https://en.wikipedia.org/wiki/Algae) species is difficult to assess,[[118]](https://en.wikipedia.org/wiki/Fungus#cite_note-Foster2002-118) the spike did not appear worldwide,[[119]](https://en.wikipedia.org/wiki/Fungus#cite_note-LopezGomez2005-119)[[120]](https://en.wikipedia.org/wiki/Fungus#cite_note-Looy2005-120) and in many places it did not fall on the Permian–Triassic boundary.[[121]](https://en.wikipedia.org/wiki/Fungus#cite_note-Ward2005-121)

## Taxonomy

Although commonly included in botany curricula and textbooks, fungi are more closely related to [animals](https://en.wikipedia.org/wiki/Animal) than to plants and are placed with the animals in the[monophyletic](https://en.wikipedia.org/wiki/Monophyletic) group of [opisthokonts](https://en.wikipedia.org/wiki/Opisthokont" \o "Opisthokont).[[122]](https://en.wikipedia.org/wiki/Fungus#cite_note-ShalchianTabrizi2008-122) Analyses using [molecular phylogenetics](https://en.wikipedia.org/wiki/Molecular_phylogenetics) support a [monophyletic](https://en.wikipedia.org/wiki/Monophyletic_group) origin of the Fungi.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42) The [taxonomy](https://en.wikipedia.org/wiki/Taxonomy_(biology)) of the Fungi is in a state of constant flux, especially due to recent research based on DNA comparisons. These current phylogenetic analyses often overturn classifications based on older and sometimes less discriminative methods based on morphological features and biological species concepts obtained from experimental [matings](https://en.wikipedia.org/wiki/Mating" \o "Mating).[[123]](https://en.wikipedia.org/wiki/Fungus#cite_note-123)

There is no unique generally accepted system at the higher taxonomic levels and there are frequent name changes at every level, from species upwards. Efforts among researchers are now underway to establish and encourage usage of a unified and more consistent [nomenclature](https://en.wikipedia.org/wiki/Botanical_nomenclature).[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42)[[124]](https://en.wikipedia.org/wiki/Fungus#cite_note-Celio2006-124) Fungal species can also have multiple scientific names depending on their life cycle and mode (sexual or asexual) of reproduction. Web sites such as [Index Fungorum](https://en.wikipedia.org/wiki/Index_Fungorum) and [ITIS](https://en.wikipedia.org/wiki/Integrated_Taxonomic_Information_System) list current names of fungal species (with cross-references to older synonyms).

The 2007 classification of Kingdom Fungi is the result of a large-scale collaborative research effort involving dozens of mycologists and other scientists working on fungal taxonomy.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42) It recognizes seven [phyla](https://en.wikipedia.org/wiki/Phylum), two of which—the Ascomycota and the Basidiomycota—are contained within a branch representing [subkingdom](https://en.wikipedia.org/wiki/Subkingdom" \o "Subkingdom)Dikarya. The above [cladogram](https://en.wikipedia.org/wiki/Cladogram" \o "Cladogram) depicts the major fungal [taxa](https://en.wikipedia.org/wiki/Taxon" \o "Taxon) and their relationship to opisthokont and unikont organisms. The lengths of the branches in this tree are not proportional to [evolutionary](https://en.wikipedia.org/wiki/Evolutionary) distances.

### Phylogeny

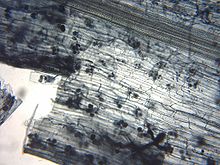
The phylogeny of Fungi based on the work of Philippe Silar[[125]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-Silar2016-125) and "The Mycota: A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research"[[126]](https://en.wikipedia.org/wiki/Fungus#cite_note-126)

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| [Holomycota](https://en.wikipedia.org/wiki/Holomycota) | |  |  | | --- | --- | |  | [Nucleariida](https://en.wikipedia.org/wiki/Nucleariida) | |  | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Opisthosporidia](https://en.wikipedia.org/w/index.php?title=Opisthosporidia&action=edit&redlink=1) | |  |  | | --- | --- | |  | [Aphelida](https://en.wikipedia.org/w/index.php?title=Aphelida&action=edit&redlink=1) | |  | |  | |  |  | | --- | --- | |  | [Cryptomycota](https://en.wikipedia.org/wiki/Cryptomycota) | |  | | [Microsporidia](https://en.wikipedia.org/wiki/Microsporidia) | |  |  | | --- | --- | |  | [Metchnikovellea](https://en.wikipedia.org/w/index.php?title=Metchnikovellea&action=edit&redlink=1) | |  | |  | [Microsporea](https://en.wikipedia.org/w/index.php?title=Microsporea&action=edit&redlink=1) | |  | | |  | | |  | | |  | | [Eumycota](https://en.wikipedia.org/wiki/Eumycota) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Chytridiomycota](https://en.wikipedia.org/wiki/Chytridiomycota) | |  |  | | --- | --- | |  | [Neocallimastigomycetes](https://en.wikipedia.org/wiki/Neocallimastigomycetes) | |  | |  | |  |  | | --- | --- | |  | [Chytridiomycetes](https://en.wikipedia.org/wiki/Chytridiomycetes) | |  | | [Monoblepharidomycotina](https://en.wikipedia.org/w/index.php?title=Monoblepharidomycotina&action=edit&redlink=1) | |  |  | | --- | --- | |  | [Hyaloraphidiomycetes](https://en.wikipedia.org/w/index.php?title=Hyaloraphidiomycetes&action=edit&redlink=1) | |  | |  | [Monoblepharidomycetes](https://en.wikipedia.org/wiki/Monoblepharidomycetes) | |  | | |  | | |  | | |  | |  | |  |  | | --- | --- | |  | [Blastocladiomycota](https://en.wikipedia.org/wiki/Blastocladiomycota) James 2007 | |  | |  | |  |  | | --- | --- | |  | [Basidiobolomycota](https://en.wikipedia.org/wiki/Basidiobolales) | |  | |  | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | [Entomophthoromycota](https://en.wikipedia.org/wiki/Entomophthoromycotina) | |  |  | | --- | --- | |  | [Neozygitomycetes](https://en.wikipedia.org/w/index.php?title=Neozygitomycetes&action=edit&redlink=1) | |  | |  | [Entomophthoromycetes](https://en.wikipedia.org/w/index.php?title=Entomophthoromycetes&action=edit&redlink=1) | |  | | |  | |  | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | [Kickxellomycota](https://en.wikipedia.org/wiki/Kickxellomycotina) | |  |  | | --- | --- | |  | [Zoopagomycetes](https://en.wikipedia.org/w/index.php?title=Zoopagomycetes&action=edit&redlink=1) | |  | |  | [Kickxellomycetes](https://en.wikipedia.org/w/index.php?title=Kickxellomycetes&action=edit&redlink=1) | |  | | |  | |  | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | [Mucoromycota](https://en.wikipedia.org/wiki/Mucoromycotina) | |  |  | | --- | --- | |  | [Mortierellomycetes](https://en.wikipedia.org/w/index.php?title=Mortierellomycetes&action=edit&redlink=1) | |  | |  | [Mucoromycetes](https://en.wikipedia.org/w/index.php?title=Mucoromycetes&action=edit&redlink=1) | |  | | |  | | [Symbiomycota](https://en.wikipedia.org/w/index.php?title=Symbiomycota&action=edit&redlink=1) | |  |  | | --- | --- | |  | [Glomeromycota](https://en.wikipedia.org/wiki/Glomeromycota) | |  | | [Dikarya](https://en.wikipedia.org/wiki/Dikarya) | |  |  | | --- | --- | |  | [Entorrhizomycota](https://en.wikipedia.org/w/index.php?title=Entorrhizomycota&action=edit&redlink=1) | |  | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  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| --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Classiculaceae](https://en.wikipedia.org/wiki/Classiculaceae) | |  | |  | [Microbotryomycetes](https://en.wikipedia.org/wiki/Microbotryomycetes) | |  | | |  | |  | |  |  | | --- | --- | |  | [Cryptomycocolacomycetes](https://en.wikipedia.org/wiki/Cryptomycocolacomycetes) | |  | |  | |  |  | | --- | --- | |  | [Atractiellomycetes](https://en.wikipedia.org/wiki/Atractiellomycetes) | |  | |  | [Pucciniomycetes](https://en.wikipedia.org/wiki/Pucciniomycetes) | |  | | |  | | |  | | |  | | |  | | |  | | [Orthomycotina](https://en.wikipedia.org/w/index.php?title=Orthomycotina&action=edit&redlink=1) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Ustilaginomycotina](https://en.wikipedia.org/wiki/Ustilaginomycotina) | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Monilielliomycetes](https://en.wikipedia.org/w/index.php?title=Monilielliomycetes&action=edit&redlink=1) | |  | |  | [Malasseziomycetes](https://en.wikipedia.org/w/index.php?title=Malasseziomycetes&action=edit&redlink=1) | |  | | |  | |  | |  |  | | --- | --- | |  | [Ustilaginomycetes](https://en.wikipedia.org/wiki/Ustilaginomycetes) | |  | |  | [Exobasidiomycetes](https://en.wikipedia.org/wiki/Exobasidiomycetes) | |  | | |  | | |  | | [Agaricomycotina](https://en.wikipedia.org/wiki/Agaricomycotina) | |  |  | | --- | --- | |  | [Wallemiomycetes](https://en.wikipedia.org/wiki/Wallemiomycetes) | |  | |  | [Bartheletiomycetes](https://en.wikipedia.org/w/index.php?title=Bartheletiomycetes&action=edit&redlink=1) | |  | |  | |  |  | | --- | --- | |  | [Tremellomycetes](https://en.wikipedia.org/wiki/Tremellomycetes) | |  | |  | |  |  | | --- | --- | |  | [Dacrymycetes](https://en.wikipedia.org/wiki/Dacrymycetes) | |  | |  | [Agaricomycetes](https://en.wikipedia.org/wiki/Agaricomycetes) | |  | | |  | | |  | | |  | | |  | | |  | | [Ascomycota](https://en.wikipedia.org/wiki/Ascomycota) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Taphrinomycotina](https://en.wikipedia.org/wiki/Taphrinomycotina) | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Neolectomycetes](https://en.wikipedia.org/wiki/Neolectomycetes) | |  | |  | [Taphrinomycetes](https://en.wikipedia.org/wiki/Taphrinomycetes) | |  | | |  | |  | |  |  | | --- | --- | |  | [Archaeorhizomycetes](https://en.wikipedia.org/wiki/Archaeorhizomycetes) | |  | |  | |  |  | | --- | --- | |  | [Pneumocystidomycetes](https://en.wikipedia.org/wiki/Pneumocystidomycetes) | |  | |  | [Schizosaccharomycetes](https://en.wikipedia.org/wiki/Schizosaccharomycetes) | |  | | |  | | |  | | |  | | [Saccharomyceta](https://en.wikipedia.org/w/index.php?title=Saccharomyceta&action=edit&redlink=1) | |  |  | | --- | --- | |  | [Saccharomycetes](https://en.wikipedia.org/wiki/Saccharomycetes) | |  | | [Pezizomycotina](https://en.wikipedia.org/wiki/Pezizomycotina) | |  |  | | --- | --- | |  | [Orbiliomycetes](https://en.wikipedia.org/wiki/Orbiliomycetes) | |  | |  | |  |  | | --- | --- | |  | [Pezizomycetes](https://en.wikipedia.org/wiki/Pezizomycetes) | |  | | [Leotiomyceta](https://en.wikipedia.org/wiki/Leotiomyceta) | |  |  | | --- | --- | |  | [Dothideomyceta](https://en.wikipedia.org/wiki/Dothideomyceta) | |  | |  | [Sordariomyceta](https://en.wikipedia.org/wiki/Sordariomyceta) | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | |
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### Taxonomic groups

*See also:*[*List of fungal orders*](https://en.wikipedia.org/wiki/List_of_fungal_orders)

The major [phyla](https://en.wikipedia.org/wiki/Phylum) (sometimes called divisions) of fungi have been classified mainly on the basis of characteristics of their sexual [reproductive](https://en.wikipedia.org/wiki/Reproduction) structures. Currently, seven phyla are proposed: Microsporidia, Chytridiomycota, Blastocladiomycota, Neocallimastigomycota, Glomeromycota, Ascomycota, and Basidiomycota.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42)

[](https://en.wikipedia.org/wiki/File:Arbuscular_mycorrhiza_microscope.jpg)

[*Arbuscular mycorrhiza*](https://en.wikipedia.org/wiki/Arbuscular_mycorrhiza) seen under microscope. [Flax](https://en.wikipedia.org/wiki/Flax) root cortical cells containing paired arbuscules.

Phylogenetic analysis has demonstrated that the [Microsporidia](https://en.wikipedia.org/wiki/Microsporidia" \o "Microsporidia), unicellular parasites of animals and protists, are fairly recent and highly derived [endobiotic](https://en.wikipedia.org/wiki/Endobiotic" \o "Endobiotic) fungi (living within the tissue of another species).[[102]](https://en.wikipedia.org/wiki/Fungus#cite_note-James2006b-102)[[127]](https://en.wikipedia.org/wiki/Fungus#cite_note-Gill2006-127) One 2006 study concludes that the Microsporidia are a sister group to the true fungi; that is, they are each other's closest evolutionary relative.[[128]](https://en.wikipedia.org/wiki/Fungus#cite_note-Liu2006-128) Hibbett and colleagues suggest that this analysis does not clash with their classification of the Fungi, and although the Microsporidia are elevated to phylum status, it is acknowledged that further analysis is required to clarify evolutionary relationships within this group.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42)

The [Chytridiomycota](https://en.wikipedia.org/wiki/Chytridiomycota" \o "Chytridiomycota) are commonly known as chytrids. These fungi are distributed worldwide. Chytrids produce [zoospores](https://en.wikipedia.org/wiki/Zoospore" \o "Zoospore)that are capable of active movement through aqueous phases with a single [flagellum](https://en.wikipedia.org/wiki/Flagellum), leading early [taxonomists](https://en.wikipedia.org/wiki/Taxonomist) to classify them as [protists](https://en.wikipedia.org/wiki/Protist" \o "Protist). [Molecular phylogenies](https://en.wikipedia.org/wiki/Molecular_phylogenetics), inferred from [rRNA](https://en.wikipedia.org/wiki/RRNA" \o "RRNA) sequences in [ribosomes](https://en.wikipedia.org/wiki/Ribosome" \o "Ribosome), suggest that the Chytrids are a [basal](https://en.wikipedia.org/wiki/Basal_(phylogenetics)" \o "Basal (phylogenetics))group divergent from the other fungal phyla, consisting of four major [clades](https://en.wikipedia.org/wiki/Clade" \o "Clade) with suggestive evidence for [paraphyly](https://en.wikipedia.org/wiki/Paraphyly" \o "Paraphyly) or possibly [polyphyly](https://en.wikipedia.org/wiki/Polyphyly" \o "Polyphyly).[[129]](https://en.wikipedia.org/wiki/Fungus#cite_note-James2006-129)

The [Blastocladiomycota](https://en.wikipedia.org/wiki/Blastocladiomycota" \o "Blastocladiomycota) were previously considered a taxonomic clade within the Chytridiomycota. Recent molecular data and [ultrastructural](https://en.wikipedia.org/wiki/Ultrastructure" \o "Ultrastructure) characteristics, however, place the Blastocladiomycota as a sister clade to the Zygomycota, Glomeromycota, and Dikarya (Ascomycota and Basidiomycota). The blastocladiomycetes are [saprotrophs](https://en.wikipedia.org/wiki/Saprotrophic_nutrition" \o "Saprotrophic nutrition), feeding on decomposing organic matter, and they are parasites of all eukaryotic groups. Unlike their close relatives, the chytrids, most of which exhibit [zygotic meiosis](https://en.wikipedia.org/wiki/Biological_life_cycle#Haplontic_life_cycle), the blastocladiomycetes undergo [sporic meiosis](https://en.wikipedia.org/wiki/Biological_life_cycle" \l "Haplodiplontic_life_cycle" \o "Biological life cycle).[[102]](https://en.wikipedia.org/wiki/Fungus#cite_note-James2006b-102)

The [Neocallimastigomycota](https://en.wikipedia.org/wiki/Neocallimastigomycota" \o "Neocallimastigomycota) were earlier placed in the phylum Chytridomycota. Members of this small phylum are [anaerobic organisms](https://en.wikipedia.org/wiki/Anaerobic_organism), living in the digestive system of larger herbivorous mammals and in other terrestrial and aquatic environments enriched in cellulose (e.g., domestic waste landfill sites).[[130]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lockhart2006-130) They lack [mitochondria](https://en.wikipedia.org/wiki/Mitochondria" \o "Mitochondria)but contain [hydrogenosomes](https://en.wikipedia.org/wiki/Hydrogenosome" \o "Hydrogenosome) of mitochondrial origin. As the related chrytrids, neocallimastigomycetes form zoospores that are posteriorly uniflagellate or polyflagellate.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42)

Members of the [Glomeromycota](https://en.wikipedia.org/wiki/Glomeromycota" \o "Glomeromycota) form [arbuscular mycorrhizae](https://en.wikipedia.org/wiki/Arbuscular_mycorrhizae" \o "Arbuscular mycorrhizae), a form of [symbiosis](https://en.wikipedia.org/wiki/Symbiosis) wherein fungal hyphae invade plant root cells and both species benefit from the resulting increased supply of nutrients. All known Glomeromycota species reproduce asexually.[[79]](https://en.wikipedia.org/wiki/Fungus" \l "cite_note-Redecker2006-79) The symbiotic association between the Glomeromycota and plants is ancient, with evidence dating to 400 million years ago.[[131]](https://en.wikipedia.org/wiki/Fungus#cite_note-Remy1994-131) Formerly part of the [Zygomycota](https://en.wikipedia.org/wiki/Zygomycota" \o "Zygomycota) (commonly known as 'sugar' and 'pin' molds), the Glomeromycota were elevated to phylum status in 2001 and now replace the older phylum Zygomycota.[[132]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schussler2001-132) Fungi that were placed in the Zygomycota are now being reassigned to the Glomeromycota, or the subphyla [incertae sedis](https://en.wikipedia.org/wiki/Incertae_sedis" \o "Incertae sedis) [Mucoromycotina](https://en.wikipedia.org/wiki/Mucoromycotina" \o "Mucoromycotina), [Kickxellomycotina](https://en.wikipedia.org/wiki/Kickxellomycotina" \o "Kickxellomycotina), the [Zoopagomycotina](https://en.wikipedia.org/wiki/Zoopagomycotina" \o "Zoopagomycotina) and the [Entomophthoromycotina](https://en.wikipedia.org/wiki/Entomophthoromycotina" \o "Entomophthoromycotina).[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42) Some well-known examples of fungi formerly in the Zygomycota include black bread mold (*[Rhizopus stolonifer](https://en.wikipedia.org/wiki/Rhizopus_stolonifer" \o "Rhizopus stolonifer)*), and *[Pilobolus](https://en.wikipedia.org/wiki/Pilobolus" \o "Pilobolus)* species, capable of ejecting [spores](https://en.wikipedia.org/wiki/Spore) several meters through the air.[[133]](https://en.wikipedia.org/wiki/Fungus#cite_note-133) Medically relevant genera include *[Mucor](https://en.wikipedia.org/wiki/Mucor" \o "Mucor)*, *[Rhizomucor](https://en.wikipedia.org/wiki/Rhizomucor" \o "Rhizomucor)*, and *[Rhizopus](https://en.wikipedia.org/wiki/Rhizopus" \o "Rhizopus)*.

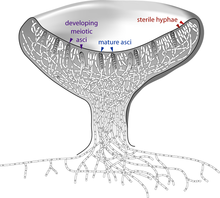
[](https://en.wikipedia.org/wiki/File:Ascocarp2.png)

Diagram of an [apothecium](https://en.wikipedia.org/wiki/Apothecium" \o "Apothecium) (the typical cup-like reproductive structure of Ascomycetes) showing sterile tissues as well as developing and mature asci.

The [Ascomycota](https://en.wikipedia.org/wiki/Ascomycota" \o "Ascomycota), commonly known as sac fungi or ascomycetes, constitute the largest taxonomic group within the Eumycota.[[41]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kirk_et_al..2C_p._489-41) These fungi form meiotic spores called [ascospores](https://en.wikipedia.org/wiki/Ascospore" \o "Ascospore), which are enclosed in a special sac-like structure called an[ascus](https://en.wikipedia.org/wiki/Ascus). This phylum includes [morels](https://en.wikipedia.org/wiki/Morel), a few [mushrooms](https://en.wikipedia.org/wiki/Mushroom) and [truffles](https://en.wikipedia.org/wiki/Tuber_(genus)), unicellular [yeasts](https://en.wikipedia.org/wiki/Yeast) (e.g., of the genera *[Saccharomyces](https://en.wikipedia.org/wiki/Saccharomyces" \o "Saccharomyces)*,[*Kluyveromyces*](https://en.wikipedia.org/wiki/Kluyveromyces), *[Pichia](https://en.wikipedia.org/wiki/Pichia" \o "Pichia)*, and [*Candida*](https://en.wikipedia.org/wiki/Candida_(genus))), and many filamentous fungi living as saprotrophs, parasites, and mutualistic symbionts. Prominent and important genera of filamentous ascomycetes include *[Aspergillus](https://en.wikipedia.org/wiki/Aspergillus" \o "Aspergillus)*, *[Penicillium](https://en.wikipedia.org/wiki/Penicillium" \o "Penicillium)*, *[Fusarium](https://en.wikipedia.org/wiki/Fusarium" \o "Fusarium)*, and[*Claviceps*](https://en.wikipedia.org/wiki/Claviceps). Many ascomycete species have only been observed undergoing asexual reproduction (called [anamorphic](https://en.wikipedia.org/wiki/Anamorph" \o "Anamorph)species), but analysis of molecular data has often been able to identify their closest [teleomorphs](https://en.wikipedia.org/wiki/Teleomorph" \o "Teleomorph) in the Ascomycota.[[134]](https://en.wikipedia.org/wiki/Fungus#cite_note-Samuels2006-134)Because the products of meiosis are retained within the sac-like ascus, ascomycetes have been used for elucidating principles of genetics and heredity (e.g., *[Neurospora crassa](https://en.wikipedia.org/wiki/Neurospora_crassa" \o "Neurospora crassa)*).[[135]](https://en.wikipedia.org/wiki/Fungus#cite_note-Radford1997-135)

Members of the [Basidiomycota](https://en.wikipedia.org/wiki/Basidiomycota" \o "Basidiomycota), commonly known as the club fungi or basidiomycetes, produce meiospores called[basidiospores](https://en.wikipedia.org/wiki/Basidiospore) on club-like stalks called [basidia](https://en.wikipedia.org/wiki/Basidium" \o "Basidium). Most common mushrooms belong to this group, as well as [rust](https://en.wikipedia.org/wiki/Rust_(fungus)) and [smut fungi](https://en.wikipedia.org/wiki/Smut_(fungus)), which are major pathogens of grains. Other important basidiomycetes include the [maize](https://en.wikipedia.org/wiki/Maize) pathogen *[Ustilago maydis](https://en.wikipedia.org/wiki/Ustilago_maydis" \o "Ustilago maydis)*,[[136]](https://en.wikipedia.org/wiki/Fungus#cite_note-Valverde1995-136)human [commensal](https://en.wikipedia.org/wiki/Commensalism" \o "Commensalism) species of the genus *[Malassezia](https://en.wikipedia.org/wiki/Malassezia" \o "Malassezia)*,[[137]](https://en.wikipedia.org/wiki/Fungus#cite_note-Zisova2009-137) and the [opportunistic](https://en.wikipedia.org/wiki/Opportunistic_infection) human pathogen, [*Cryptococcus neoformans*](https://en.wikipedia.org/wiki/Cryptococcus_neoformans).[[138]](https://en.wikipedia.org/wiki/Fungus#cite_note-Perfect2006-138)

### Fungus-like organisms

Because of similarities in morphology and lifestyle, the [slime molds](https://en.wikipedia.org/wiki/Slime_mold) ([mycetozoans](https://en.wikipedia.org/wiki/Mycetozoa), [plasmodiophorids](https://en.wikipedia.org/wiki/Plasmodiophorid), [acrasids](https://en.wikipedia.org/wiki/Acrasid), [*Fonticula*](https://en.wikipedia.org/wiki/Fonticula) and [labyrinthulids](https://en.wikipedia.org/wiki/Labyrinthulid), now in [Amoebozoa](https://en.wikipedia.org/wiki/Amoebozoa" \o "Amoebozoa),[Rhizaria](https://en.wikipedia.org/wiki/Rhizaria), [Excavata](https://en.wikipedia.org/wiki/Excavata" \o "Excavata), [Opisthokonta](https://en.wikipedia.org/wiki/Opisthokonta" \o "Opisthokonta) and [Stramenopiles](https://en.wikipedia.org/wiki/Stramenopiles" \o "Stramenopiles), respectively), water molds ([oomycetes](https://en.wikipedia.org/wiki/Oomycete" \o "Oomycete)) and [hyphochytrids](https://en.wikipedia.org/wiki/Hyphochytrid" \o "Hyphochytrid) (both [Stramenopiles](https://en.wikipedia.org/wiki/Stramenopiles" \o "Stramenopiles)) were formerly classified in the kingdom Fungi, in groups like [Mastigomycotina](https://en.wikipedia.org/wiki/Mastigomycotina" \o "Mastigomycotina), [Gymnomycota](https://en.wikipedia.org/wiki/Gymnomycota" \o "Gymnomycota) and [Phycomycetes](https://en.wikipedia.org/wiki/Phycomycetes" \o "Phycomycetes). The slime molds were studied also as [protozoans](https://en.wikipedia.org/wiki/Protozoa" \o "Protozoa), leading to a [ambiregnal](https://en.wikipedia.org/wiki/Ambiregnal" \o "Ambiregnal), duplicated taxonomy.

Unlike true fungi, the [cell walls](https://en.wikipedia.org/wiki/Cell_wall) of oomycetes contain [cellulose](https://en.wikipedia.org/wiki/Cellulose) and lack [chitin](https://en.wikipedia.org/wiki/Chitin). Hyphochytrids have both chitin and cellulose. Slime molds lack a cell wall during the assimilative phase (except labyrinthulids, which have a wall of scales), and ingest nutrients by ingestion ([phagocytosis](https://en.wikipedia.org/wiki/Phagocytosis" \o "Phagocytosis), except labyrinthulids) rather than absorption ([osmotrophy](https://en.wikipedia.org/wiki/Osmotrophy" \o "Osmotrophy), as fungi, labyrinthulids, oomycetes and hyphochytrids). Neither water molds nor slime molds are closely related to the true fungi, and, therefore,[taxonomists](https://en.wikipedia.org/wiki/Taxonomist" \o "Taxonomist) no longer group them in the kingdom Fungi. Nonetheless, studies of the oomycetes and myxomycetes are still often included in [mycology](https://en.wikipedia.org/wiki/Mycology) textbooks and primary research literature.[[139]](https://en.wikipedia.org/wiki/Fungus#cite_note-Blackwell2004-139)

The [Eccrinales](https://en.wikipedia.org/wiki/Eccrinales" \o "Eccrinales) and [Amoebidiales](https://en.wikipedia.org/wiki/Amoebidiales" \o "Amoebidiales) are [opisthokont](https://en.wikipedia.org/wiki/Opisthokont" \o "Opisthokont) [protists](https://en.wikipedia.org/wiki/Protist" \o "Protist), previously thought to be zygomycete fungi. Other groups now in [Opisthokonta](https://en.wikipedia.org/wiki/Opisthokonta" \o "Opisthokonta) (e.g., *[Corallochytrium](https://en.wikipedia.org/wiki/Corallochytrium" \o "Corallochytrium)*,[Ichthyosporea](https://en.wikipedia.org/wiki/Ichthyosporea" \o "Ichthyosporea)) were also at given time classified as fungi. The genus *[Blastocystis](https://en.wikipedia.org/wiki/Blastocystis" \o "Blastocystis)*, now in [Stramenopiles](https://en.wikipedia.org/wiki/Stramenopiles" \o "Stramenopiles), was originally classified as a yeast. *[Ellobiopsis](https://en.wikipedia.org/wiki/Ellobiopsis" \o "Ellobiopsis)*, now in[Alveolata](https://en.wikipedia.org/wiki/Alveolata), was considered a chytrid. The [bacteria](https://en.wikipedia.org/wiki/Bacteria) were also included in fungi in some classifications, as the group Schizomycetes.

The [Rozellida](https://en.wikipedia.org/wiki/Rozellida" \o "Rozellida) clade, including the "ex-chytrid" *[Rozella](https://en.wikipedia.org/wiki/Rozella" \o "Rozella)*, is a genetically disparate group known mostly from environmental DNA sequences that is a sister group to fungi. Members of the group that have been isolated lack the chitinous cell wall that is characteristic of fungi.

The [nucleariids](https://en.wikipedia.org/wiki/Nucleariid" \o "Nucleariid), protists currently grouped in the [Choanozoa](https://en.wikipedia.org/wiki/Choanozoa" \o "Choanozoa) ([Opisthokonta](https://en.wikipedia.org/wiki/Opisthokonta" \o "Opisthokonta)), may be the next sister group to the eumycete clade, and as such could be included in an expanded fungal kingdom.[[140]](https://en.wikipedia.org/wiki/Fungus#cite_note-Tabrizi2008-140)

## Ecology

[](https://en.wikipedia.org/wiki/File:PinMould_on_Peach_LowMag_Scale.jpg)

A pin mold decomposing a peach

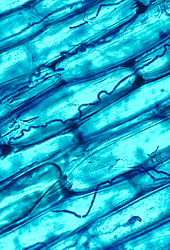
Although often inconspicuous, fungi occur in every environment on [Earth](https://en.wikipedia.org/wiki/Earth) and play very important roles in most [ecosystems](https://en.wikipedia.org/wiki/Ecosystems). Along with bacteria, fungi are the major [decomposers](https://en.wikipedia.org/wiki/Decomposers) in most terrestrial (and some aquatic) ecosystems, and therefore play a critical role in [biogeochemical cycles](https://en.wikipedia.org/wiki/Biogeochemical_cycles)[[141]](https://en.wikipedia.org/wiki/Fungus#cite_note-Gadd2007-141) and in many [food webs](https://en.wikipedia.org/wiki/Food_webs). As decomposers, they play an essential role in [nutrient cycling](https://en.wikipedia.org/wiki/Nutrient_cycling), especially as [saprotrophs](https://en.wikipedia.org/wiki/Saprotroph" \o "Saprotroph) and [symbionts](https://en.wikipedia.org/wiki/Symbiont" \o "Symbiont), degrading [organic matter](https://en.wikipedia.org/wiki/Organic_matter) to inorganic molecules, which can then re-enter anabolic metabolic pathways in plants or other organisms.[[142]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lindahl2007-142)[[143]](https://en.wikipedia.org/wiki/Fungus#cite_note-Barea2005-143)

### Symbiosis

Many fungi have important [symbiotic](https://en.wikipedia.org/wiki/Symbiotic) relationships with organisms from most if not all [Kingdoms](https://en.wikipedia.org/wiki/Kingdom_(biology)).[[144]](https://en.wikipedia.org/wiki/Fungus#cite_note-Aanen2006-144)[[145]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nikoh2000-145)[[146]](https://en.wikipedia.org/wiki/Fungus#cite_note-Perotto1997-146) These interactions can be [mutualistic](https://en.wikipedia.org/wiki/Mutualism_(biology)" \o "Mutualism (biology)) or antagonistic in nature, or in the case of [commensal](https://en.wikipedia.org/wiki/Commensal" \o "Commensal) fungi are of no apparent benefit or detriment to the host.[[147]](https://en.wikipedia.org/wiki/Fungus#cite_note-Arnold2003-147)[[148]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paszkowski2006-148)[[149]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hube2004-149)

#### With plants

[Mycorrhizal](https://en.wikipedia.org/wiki/Mycorrhiza) symbiosis between [plants](https://en.wikipedia.org/wiki/Plants) and fungi is one of the most well-known plant–fungus associations and is of significant importance for plant growth and persistence in many ecosystems; over 90% of all plant species engage in mycorrhizal relationships with fungi and are dependent upon this relationship for survival.[[150]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bonfante2003-150)

[](https://en.wikipedia.org/wiki/File:Neotyphodium_coenophialum.jpg)

The dark filaments are[hyphae](https://en.wikipedia.org/wiki/Hyphae) of the endophytic fungus *[Neotyphodium coenophialum](https://en.wikipedia.org/wiki/Neotyphodium_coenophialum" \o "Neotyphodium coenophialum)* in the intercellular spaces of [tall fescue](https://en.wikipedia.org/wiki/Festuca_arundinacea) leaf sheath tissue

The mycorrhizal symbiosis is ancient, dating to at least 400 million years ago.[[131]](https://en.wikipedia.org/wiki/Fungus#cite_note-Remy1994-131) It often increases the plant's uptake of inorganic compounds, such as [nitrate](https://en.wikipedia.org/wiki/Nitrate) and [phosphate](https://en.wikipedia.org/wiki/Phosphate) from soils having low concentrations of these key plant nutrients.[[142]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lindahl2007-142)[[151]](https://en.wikipedia.org/wiki/Fungus#cite_note-Heijden2006-151) The fungal partners may also mediate plant-to-plant transfer of carbohydrates and other nutrients. Such mycorrhizal communities are called "common mycorrhizal networks".[[152]](https://en.wikipedia.org/wiki/Fungus#cite_note-Selosse2006-152) A special case of mycorrhiza is [myco-heterotrophy](https://en.wikipedia.org/wiki/Myco-heterotrophy" \o "Myco-heterotrophy), whereby the plant parasitizes the fungus, obtaining all of its nutrients from its fungal symbiont.[[153]](https://en.wikipedia.org/wiki/Fungus#cite_note-Merckx2009-153) Some fungal species inhabit the tissues inside roots, stems, and leaves, in which case they are called endophytes.[[154]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schulz2005-154) Similar to mycorrhiza, endophytic colonization by fungi may benefit both symbionts; for example, endophytes of grasses impart to their host increased resistance to herbivores and other environmental stresses and receive food and shelter from the plant in return.[[155]](https://en.wikipedia.org/wiki/Fungus#cite_note-Clay2002-155)

#### With algae and cyanobacteria

[](https://en.wikipedia.org/wiki/File:Lobaria_pulmonaria_010108a.jpg)

The lichen *[Lobaria pulmonaria](https://en.wikipedia.org/wiki/Lobaria_pulmonaria" \o "Lobaria pulmonaria)*, a symbiosis of fungal, [algal](https://en.wikipedia.org/wiki/Algae), and[cyanobacterial](https://en.wikipedia.org/wiki/Cyanobacteria) species

[Lichens](https://en.wikipedia.org/wiki/Lichens) are a symbiotic relationship between fungi and [algae](https://en.wikipedia.org/wiki/Algae) or [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria" \o "Cyanobacteria). The algae partner in the relationship is referred to in lichen terminology as a "photobiont". The fungi part of the relationship are composed mostly of various species of [ascomycetes](https://en.wikipedia.org/wiki/Ascomycete" \o "Ascomycete) and a few[basidiomycetes](https://en.wikipedia.org/wiki/Basidiomycete).[[156]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brodo2001-156) Lichens occur in every ecosystem on all continents, play a key role in[soil formation](https://en.wikipedia.org/wiki/Soil_formation) and the initiation of [biological succession](https://en.wikipedia.org/wiki/Ecological_succession),[[157]](https://en.wikipedia.org/wiki/Fungus#cite_note-Raven2005-157) and are the dominating life forms in extreme environments, including [polar](https://en.wikipedia.org/wiki/Polar_region), [alpine](https://en.wikipedia.org/wiki/Alpine_climate), and [semiarid](https://en.wikipedia.org/wiki/Semiarid_climate) desert regions.[[158]](https://en.wikipedia.org/wiki/Fungus#cite_note-158) They are able to grow on inhospitable surfaces, including bare soil, rocks, [tree bark](https://en.wikipedia.org/wiki/Bark), wood, shells, barnacles and leaves.[[159]](https://en.wikipedia.org/wiki/Fungus#cite_note-Purvis2000-159) As in [mycorrhizas](https://en.wikipedia.org/wiki/Mycorrhiza" \o "Mycorrhiza), the photobiont provides sugars and other carbohydrates via [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis) to the fungus, while the fungus provides minerals and water to the photobiont. The functions of both symbiotic organisms are so closely intertwined that they function almost as a single organism; in most cases the resulting organism differs greatly from the individual components. Lichenization is a common mode of nutrition for fungi; around 20% of fungi—between 17,500 and 20,000 described species—are lichenized.[[160]](https://en.wikipedia.org/wiki/Fungus#cite_note-160) Characteristics common to most lichens include obtaining [organic carbon](https://en.wikipedia.org/wiki/Organic_carbon) by photosynthesis, slow growth, small size, long life, long-lasting (seasonal) [vegetative reproductive](https://en.wikipedia.org/wiki/Vegetative_reproduction) structures, mineral nutrition obtained largely from airborne sources, and greater tolerance of [desiccation](https://en.wikipedia.org/wiki/Desiccation) than most other photosynthetic organisms in the same habitat.[[161]](https://en.wikipedia.org/wiki/Fungus#cite_note-161)

#### With insects

Many insects also engage in [mutualistic relationships](https://en.wikipedia.org/wiki/Ant-fungus_mutualism" \o "Ant-fungus mutualism) with fungi. Several groups of ants cultivate fungi in the order [Agaricales](https://en.wikipedia.org/wiki/Agaricales" \o "Agaricales) as their primary food source, while[ambrosia beetles](https://en.wikipedia.org/wiki/Ambrosia_beetles) cultivate various species of fungi in the bark of trees that they infest.[[162]](https://en.wikipedia.org/wiki/Fungus#cite_note-Douglas1989-162) Likewise, females of several [wood wasp](https://en.wikipedia.org/wiki/Wood_wasp) species (genus *[Sirex](https://en.wikipedia.org/wiki/Sirex" \o "Sirex)*) inject their eggs together with spores of the wood-rotting fungus *Amylostereum areolatum* into the [sapwood](https://en.wikipedia.org/wiki/Wood#Heartwood_and_sapwood) of [pine](https://en.wikipedia.org/wiki/Pine) trees; the growth of the fungus provides ideal nutritional conditions for the development of the wasp larvae.[[163]](https://en.wikipedia.org/wiki/Fungus#cite_note-163) At least one species of [stingless bee](https://en.wikipedia.org/wiki/Stingless_bee) has a relationship with a fungus in the genus *[Monascus](https://en.wikipedia.org/wiki/Monascus" \o "Monascus)*, where the larvae consume and depend on fungus transferred from old to new nests.[[164]](https://en.wikipedia.org/wiki/Fungus#cite_note-Sci-News2015-164) [Termites](https://en.wikipedia.org/wiki/Termites) on the African [savannah](https://en.wikipedia.org/wiki/Savannah) are also known to cultivate fungi,[[144]](https://en.wikipedia.org/wiki/Fungus#cite_note-Aanen2006-144) and yeasts of the genera [*Candida*](https://en.wikipedia.org/wiki/Candida_(genus)) and *Lachancea* inhabit the [gut](https://en.wikipedia.org/wiki/Gastrointestinal_tract) of a wide range of insects, including [neuropterans](https://en.wikipedia.org/wiki/Neuroptera), [beetles](https://en.wikipedia.org/wiki/Beetle), and [cockroaches](https://en.wikipedia.org/wiki/Cockroach); it is not known whether these fungi benefit their hosts.[[165]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nguyen2007-165) The larvae of many families of fungicolous flies, particularly those within the superfamily [Sciaroidea](https://en.wikipedia.org/wiki/Sciaroidea" \o "Sciaroidea) such as the [Mycetophilidae](https://en.wikipedia.org/wiki/Mycetophilidae" \o "Mycetophilidae) and some[Keroplatidae](https://en.wikipedia.org/wiki/Keroplatidae) feed on fungal fruiting bodies and sterile [mycorrhizae](https://en.wikipedia.org/wiki/Mycorrhizae" \o "Mycorrhizae).[[166]](https://en.wikipedia.org/wiki/Fungus#cite_note-Chandler2010-166)

#### As pathogens and parasites

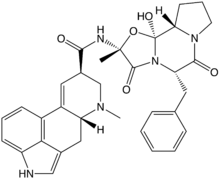
[](https://en.wikipedia.org/wiki/File:Aecidium_magnellanicum.jpg)

The plant pathogen *Aecidium magellanicum* causes [calafate rust](https://en.wikipedia.org/wiki/Calafate_rust" \o "Calafate rust), seen here on a *[Berberis](https://en.wikipedia.org/wiki/Berberis" \o "Berberis)* shrub in Chile.

Many fungi are [parasites](https://en.wikipedia.org/wiki/Parasite) on plants, animals (including humans), and other fungi. Serious pathogens of many cultivated plants causing extensive damage and losses to agriculture and forestry include the [rice blast](https://en.wikipedia.org/wiki/Rice_blast) fungus *[Magnaporthe oryzae](https://en.wikipedia.org/wiki/Magnaporthe_oryzae" \o "Magnaporthe oryzae)*,[[167]](https://en.wikipedia.org/wiki/Fungus#cite_note-Talbot2003-167) tree pathogens such as *[Ophiostoma ulmi](https://en.wikipedia.org/wiki/Ophiostoma_ulmi" \o "Ophiostoma ulmi)* and *[Ophiostoma novo-ulmi](https://en.wikipedia.org/wiki/Ophiostoma_novo-ulmi" \o "Ophiostoma novo-ulmi)* causing [Dutch elm disease](https://en.wikipedia.org/wiki/Dutch_elm_disease),[[168]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paoletti2006-168) and[*Cryphonectria parasitica*](https://en.wikipedia.org/wiki/Cryphonectria_parasitica) responsible for [chestnut blight](https://en.wikipedia.org/wiki/Chestnut_blight),[[169]](https://en.wikipedia.org/wiki/Fungus#cite_note-Gryzenhout2006-169) and plant pathogens in the genera *[Fusarium](https://en.wikipedia.org/wiki/Fusarium" \o "Fusarium)*, *[Ustilago](https://en.wikipedia.org/wiki/Ustilago" \o "Ustilago)*,[*Alternaria*](https://en.wikipedia.org/wiki/Alternaria), and *[Cochliobolus](https://en.wikipedia.org/wiki/Cochliobolus" \o "Cochliobolus)*.[[148]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paszkowski2006-148) Some [carnivorous fungi](https://en.wikipedia.org/wiki/Carnivorous_fungi), like *[Paecilomyces lilacinus](https://en.wikipedia.org/wiki/Paecilomyces_lilacinus" \o "Paecilomyces lilacinus)*, are [predators](https://en.wikipedia.org/wiki/Nematophagous_fungus) of [nematodes](https://en.wikipedia.org/wiki/Nematodes), which they capture using an array of specialized structures such as constricting rings or adhesive nets.[[170]](https://en.wikipedia.org/wiki/Fungus#cite_note-Yang2007-170)

Some fungi can cause serious diseases in humans, several of which may be fatal if untreated. These include [aspergilloses](https://en.wikipedia.org/wiki/Aspergillosis),[candidoses](https://en.wikipedia.org/wiki/Candidosis), [coccidioidomycosis](https://en.wikipedia.org/wiki/Coccidioidomycosis), [cryptococcosis](https://en.wikipedia.org/wiki/Cryptococcosis), [histoplasmosis](https://en.wikipedia.org/wiki/Histoplasmosis), [mycetomas](https://en.wikipedia.org/wiki/Eumycetoma), and [paracoccidioidomycosis](https://en.wikipedia.org/wiki/Paracoccidioidomycosis" \o "Paracoccidioidomycosis). Furthermore, persons with [immuno-deficiencies](https://en.wikipedia.org/wiki/Immunodeficiency" \o "Immunodeficiency) are particularly susceptible to disease by genera such as [*Aspergillus*](https://en.wikipedia.org/wiki/Aspergillus), [*Candida*](https://en.wikipedia.org/wiki/Candida_(genus)),[*Cryptoccocus*](https://en.wikipedia.org/wiki/Cryptococcus_neoformans),[[149]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hube2004-149)[[171]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nielsen2007-171)[[172]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brakhage2005-172) [*Histoplasma*](https://en.wikipedia.org/wiki/Histoplasma),[[173]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kauffman2007-173) and [*Pneumocystis*](https://en.wikipedia.org/wiki/Pneumocystis).[[174]](https://en.wikipedia.org/wiki/Fungus#cite_note-Cushion2007-174) Other fungi can attack eyes, nails, hair, and especially skin, the so-called [dermatophytic](https://en.wikipedia.org/wiki/Dermatophyte" \o "Dermatophyte) and keratinophilic fungi, and cause local infections such as [ringworm](https://en.wikipedia.org/wiki/Ringworm) and [athlete's foot](https://en.wikipedia.org/wiki/Athlete%27s_foot).[[175]](https://en.wikipedia.org/wiki/Fungus#cite_note-Cook2008-175)Fungal spores are also a cause of [allergies](https://en.wikipedia.org/wiki/Allergies), and fungi from different taxonomic groups can evoke allergic reactions.[[176]](https://en.wikipedia.org/wiki/Fungus#cite_note-SimonNobbe2008-176)

## Mycotoxins

[](https://en.wikipedia.org/wiki/File:Ergotamine3.png)

[Ergotamine](https://en.wikipedia.org/wiki/Ergotamine), a major mycotoxin produced by *[Claviceps](https://en.wikipedia.org/wiki/Claviceps" \o "Claviceps)* species, which if ingested can cause [gangrene](https://en.wikipedia.org/wiki/Gangrene), convulsions, and [hallucinations](https://en.wikipedia.org/wiki/Hallucination)

Many fungi produce [biologically active](https://en.wikipedia.org/wiki/Biological_activity) compounds, several of which are [toxic](https://en.wikipedia.org/wiki/Toxin) to animals or plants and are therefore called[mycotoxins](https://en.wikipedia.org/wiki/Mycotoxins). Of particular relevance to humans are mycotoxins produced by molds causing food spoilage, and poisonous mushrooms (see above). Particularly infamous are the lethal [amatoxins](https://en.wikipedia.org/wiki/Amatoxin" \o "Amatoxin) in some [*Amanita*](https://en.wikipedia.org/wiki/Amanita) mushrooms, and [ergot alkaloids](https://en.wikipedia.org/wiki/Ergotamine), which have a long history of causing serious epidemics of [ergotism](https://en.wikipedia.org/wiki/Ergotism" \o "Ergotism) (St Anthony's Fire) in people consuming [rye](https://en.wikipedia.org/wiki/Rye) or related[cereals](https://en.wikipedia.org/wiki/Cereal) contaminated with [sclerotia](https://en.wikipedia.org/wiki/Sclerotia" \o "Sclerotia) of the ergot fungus, *[Claviceps purpurea](https://en.wikipedia.org/wiki/Claviceps_purpurea" \o "Claviceps purpurea)*.[[177]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schardl2007-177) Other notable mycotoxins include the[aflatoxins](https://en.wikipedia.org/wiki/Aflatoxin), which are insidious [liver toxins](https://en.wikipedia.org/wiki/Hepatotoxicity) and highly [carcinogenic](https://en.wikipedia.org/wiki/Carcinogenic) metabolites produced by certain *[Aspergillus](https://en.wikipedia.org/wiki/Aspergillus" \o "Aspergillus)* species often growing in or on grains and nuts consumed by humans, [ochratoxins](https://en.wikipedia.org/wiki/Ochratoxin" \o "Ochratoxin), [patulin](https://en.wikipedia.org/wiki/Patulin" \o "Patulin), and [trichothecenes](https://en.wikipedia.org/wiki/Trichothecene" \o "Trichothecene) (e.g., [T-2 mycotoxin](https://en.wikipedia.org/wiki/T-2_mycotoxin)) and[fumonisins](https://en.wikipedia.org/wiki/Fumonisin), which have significant impact on human food supplies or animal [livestock](https://en.wikipedia.org/wiki/Livestock).[[178]](https://en.wikipedia.org/wiki/Fungus#cite_note-vanEgmond2007-178)

Mycotoxins are secondary metabolites (or [natural products](https://en.wikipedia.org/wiki/Natural_product)), and research has established the existence of biochemical pathways solely for the purpose of producing mycotoxins and other natural products in fungi.[[28]](https://en.wikipedia.org/wiki/Fungus#cite_note-Keller2005-28) Mycotoxins may provide[fitness](https://en.wikipedia.org/wiki/Fitness_(biology)) benefits in terms of physiological adaptation, competition with other microbes and fungi, and protection from consumption ([fungivory](https://en.wikipedia.org/wiki/Fungivore" \o "Fungivore)).[[179]](https://en.wikipedia.org/wiki/Fungus#cite_note-Demain2000-179)[[180]](https://en.wikipedia.org/wiki/Fungus#cite_note-Rohlfs2007-180)

## Pathogenic mechanisms:*[Ustilago maydis](https://en.wikipedia.org/wiki/Ustilago_maydis" \o "Ustilago maydis)* is a pathogenic plant fungus that causes smut disease in maize and [teosinte](https://en.wikipedia.org/wiki/Teosinte" \o "Teosinte). Plants have evolved efficient defense systems against pathogenic microbes such as *U. maydis*. A rapid defense reaction after pathogen attack is the [oxidative burst](https://en.wikipedia.org/wiki/Oxidative_burst) where the plant produces [reactive oxygen species](https://en.wikipedia.org/wiki/Reactive_oxygen_species) at the site of the attempted invasion. *U. maydis* can respond to the oxidative burst with an oxidative stress response, regulated by the gene [*YAP1*](https://en.wikipedia.org/wiki/YAP1). The response protects *U. maydis*from the host defense, and is necessary for the pathogen’s virulence. Furthermore, *U. maydis* has a well-established recombinational [DNA repair](https://en.wikipedia.org/wiki/DNA_repair) system which acts during mitosis and meiosis. The system may assist the pathogen in surviving DNA damage arising from the host plant’s oxidative defensive response to infection.

[*Cryptococcus neoformans*](https://en.wikipedia.org/wiki/Cryptococcus_neoformans) is an encapsulated yeast that can live in both plants and animals. *C. neoformans* usually infects the lungs, where it is phagocytosed by[alveolar macrophages](https://en.wikipedia.org/wiki/Alveolar_macrophage). Some *C. neoformans* can survive [inside](https://en.wikipedia.org/wiki/Intracellular) macrophage, which appears to be the basis for [latency](https://en.wikipedia.org/wiki/Latency_period), disseminated disease, and resistance to antifungal agents. One mechanism by which *C. neoformans* survives the hostile macrophage environment is by up-regulating the expression of genes involved in the oxidative stress response. Another mechanism involves [meiosis](https://en.wikipedia.org/wiki/Meiosis). The majority of *C. neoformans* are mating "type a". Filaments of mating "type a" ordinarily have haploid nuclei, but they can become diploid (perhaps by endoduplication or by stimulated nuclear fusion) to form [blastospores](https://en.wikipedia.org/wiki/Blastospore" \o "Blastospore). The diploid nuclei of blastospores can undergo meiosis, including recombination, to form haploid basidiospores that can be dispersed. This process is referred to as monokaryotic fruiting. this process requires a gene called [*DMC1*](https://en.wikipedia.org/wiki/DMC1), which is a conserved homologue of genes *[recA](https://en.wikipedia.org/wiki/RecA" \o "RecA)* in bacteria and [*RAD51*](https://en.wikipedia.org/wiki/RAD51) in eukaryotes, that mediates homologous chromosome pairing during meiosis and repair of DNA double-strand breaks. Thus, *C. neoformans* can undergo a meiosis, monokaryotic fruiting, that promotes recombinational repair in the oxidative, DNA damaging environment of the host macrophage, and the repair capability may contribute to its virulence.

## Human use:The human use of fungi for food preparation or preservation and other purposes is extensive and has a long history. [Mushroom farming](https://en.wikipedia.org/wiki/Mushroom_farming) and [mushroom gathering](https://en.wikipedia.org/wiki/Mushroom_gathering) are large industries in many countries. The study of the historical uses and sociological impact of fungi is known as [ethnomycology](https://en.wikipedia.org/wiki/Ethnomycology" \o "Ethnomycology). Because of the capacity of this group to produce an enormous range of [natural products](https://en.wikipedia.org/wiki/Natural_products) with [antimicrobial](https://en.wikipedia.org/wiki/Antimicrobial) or other biological activities, many species have long been used or are being developed for industrial [production of antibiotics](https://en.wikipedia.org/wiki/Production_of_antibiotics), vitamins, and [anti-cancer](https://en.wikipedia.org/wiki/Taxol#Production) and [cholesterol-lowering](https://en.wikipedia.org/wiki/Lovastatin) drugs. More recently, methods have been developed for [genetic engineering](https://en.wikipedia.org/wiki/Genetic_engineering) of fungi, enabling [metabolic engineering](https://en.wikipedia.org/wiki/Metabolic_engineering) of fungal species. For example, genetic modification of yeast species—which are easy to grow at fast rates in large fermentation vessels—has opened up ways of [pharmaceutical](https://en.wikipedia.org/wiki/Pharmaceutical) production that are potentially more efficient than production by the original source organisms.

### Therapeutic uses

#### Modern chemotherapeutics: Many species produce metabolites that are major sources of [pharmacologically](https://en.wikipedia.org/wiki/Pharmacology) active drugs. Particularly important are the antibiotics, including the [penicillins](https://en.wikipedia.org/wiki/Penicillin" \o "Penicillin), a structurally related group of [β-lactam antibiotics](https://en.wikipedia.org/wiki/%CE%92-lactam_antibiotic) that are synthesized from small [peptides](https://en.wikipedia.org/wiki/Peptide). Although naturally occurring penicillins such as [penicillin G](https://en.wikipedia.org/wiki/Penicillin_G) (produced by *[Penicillium chrysogenum](https://en.wikipedia.org/wiki/Penicillium_chrysogenum" \o "Penicillium chrysogenum)*) have a relatively narrow spectrum of biological activity, a wide range of other penicillins can be produced by [chemical modification](https://en.wikipedia.org/wiki/Chemical_synthesis) of the natural penicillins. Modern penicillins are [semisynthetic](https://en.wikipedia.org/wiki/Semisynthesis" \o "Semisynthesis) compounds, obtained initially from [fermentation](https://en.wikipedia.org/wiki/Fermentation_(biochemistry)) cultures, but then structurally altered for specific desirable properties. Other antibiotics produced by fungi include: [ciclosporin](https://en.wikipedia.org/wiki/Ciclosporin" \o "Ciclosporin), commonly used as an [immunosuppressant](https://en.wikipedia.org/wiki/Immunosuppressant) during[transplant surgery](https://en.wikipedia.org/wiki/Organ_transplant); and [fusidic acid](https://en.wikipedia.org/wiki/Fusidic_acid" \o "Fusidic acid), used to help control infection from [methicillin-resistant](https://en.wikipedia.org/wiki/Methicillin-resistant_Staphylococcus_aureus" \o "Methicillin-resistant Staphylococcus aureus)*[Staphylococcus aureus](https://en.wikipedia.org/wiki/Methicillin-resistant_Staphylococcus_aureus" \o "Methicillin-resistant Staphylococcus aureus)* bacteria. Widespread use of antibiotics for the treatment of bacterial diseases, such as [tuberculosis](https://en.wikipedia.org/wiki/Tuberculosis), [syphilis](https://en.wikipedia.org/wiki/Syphilis), [leprosy](https://en.wikipedia.org/wiki/Leprosy), and others began in the early 20th century and continues to date. In nature, antibiotics of fungal or bacterial origin appear to play a dual role: at high concentrations they act as chemical defense against competition with other microorganisms in species-rich environments, such as the [rhizosphere](https://en.wikipedia.org/wiki/Rhizosphere_(ecology)" \o "Rhizosphere (ecology)), and at low concentrations as [quorum-sensing](https://en.wikipedia.org/wiki/Quorum_sensing) molecules for intra- or interspecies signaling. Other drugs produced by fungi include [griseofulvin](https://en.wikipedia.org/wiki/Griseofulvin" \o "Griseofulvin) isolated from *[Penicillium griseofulvum](https://en.wikipedia.org/wiki/Penicillium_griseofulvum" \o "Penicillium griseofulvum)*, used to treat fungal infections, and [statins](https://en.wikipedia.org/wiki/Statin" \o "Statin) ([HMG-CoA reductase](https://en.wikipedia.org/wiki/HMG-CoA_reductase) inhibitors), used to inhibit[cholesterol synthesis](https://en.wikipedia.org/wiki/Cholesterol_synthesis). Examples of statins found in fungi include [mevastatin](https://en.wikipedia.org/wiki/Mevastatin" \o "Mevastatin) from *Penicillium citrinum* and [lovastatin](https://en.wikipedia.org/wiki/Lovastatin" \o "Lovastatin) from *[Aspergillus terreus](https://en.wikipedia.org/wiki/Aspergillus_terreus" \o "Aspergillus terreus)* and the [oyster mushroom](https://en.wikipedia.org/wiki/Pleurotus_ostreatus).

#### Traditional and folk medicine :Certain mushrooms enjoy usage as therapeutics in [folk medicines](https://en.wikipedia.org/wiki/Folk_medicine), such as [Traditional Chinese medicine](https://en.wikipedia.org/wiki/Traditional_Chinese_medicine). Notable medicinal mushrooms with a well-documented history of use include *[Agaricus subrufescens](https://en.wikipedia.org/wiki/Agaricus_subrufescens" \o "Agaricus subrufescens)*, *[Ganoderma lucidum](https://en.wikipedia.org/wiki/Ganoderma_lucidum" \o "Ganoderma lucidum)*, and[*Ophiocordyceps sinensis*](https://en.wikipedia.org/wiki/Ophiocordyceps_sinensis). Research has identified compounds produced by these and other fungi that have inhibitory biological effects against [viruses](https://en.wikipedia.org/wiki/Virus) and [cancer cells](https://en.wikipedia.org/wiki/Cancer_cells). Specific metabolites, such as [polysaccharide-K](https://en.wikipedia.org/wiki/Polysaccharide-K),[ergotamine](https://en.wikipedia.org/wiki/Ergotamine" \o "Ergotamine), and [β-lactam antibiotics](https://en.wikipedia.org/wiki/Beta-lactam_antibiotic), are routinely used in clinical medicine. The [shiitake](https://en.wikipedia.org/wiki/Shiitake) mushroom is a source of [lentinan](https://en.wikipedia.org/wiki/Lentinan" \o "Lentinan), a clinical drug approved for use in cancer treatments in several countries, including [Japan](https://en.wikipedia.org/wiki/Japan). In [Europe](https://en.wikipedia.org/wiki/Europe) and [Japan](https://en.wikipedia.org/wiki/Japan" \o "Japan),[polysaccharide-K](https://en.wikipedia.org/wiki/Polysaccharide-K) (brand name Krestin), a chemical derived from *[Trametes versicolor](https://en.wikipedia.org/wiki/Trametes_versicolor" \o "Trametes versicolor)*, is an approved [adjuvant](https://en.wikipedia.org/wiki/Adjuvant) for cancer therapy.

### Cultured foods :[Baker's yeast](https://en.wikipedia.org/wiki/Baker%27s_yeast) or *[Saccharomyces cerevisiae](https://en.wikipedia.org/wiki/Saccharomyces_cerevisiae" \o "Saccharomyces cerevisiae)*, a unicellular fungus, is used to make [bread](https://en.wikipedia.org/wiki/Bread) and other wheat-based products, such as [pizza](https://en.wikipedia.org/wiki/Pizza) dough and [dumplings](https://en.wikipedia.org/wiki/Dumpling).Yeast species of the genus *[Saccharomyces](https://en.wikipedia.org/wiki/Saccharomyces" \o "Saccharomyces)* are also used to produce [alcoholic beverages](https://en.wikipedia.org/wiki/Alcoholic_beverage) through fermentation. Shoyu koji mold (*[Aspergillus oryzae](https://en.wikipedia.org/wiki/Aspergillus_oryzae" \o "Aspergillus oryzae)*) is an essential ingredient in brewing [Shoyu](https://en.wikipedia.org/wiki/Shoyu" \o "Shoyu) ([soy sauce](https://en.wikipedia.org/wiki/Soy_sauce)) and [sake](https://en.wikipedia.org/wiki/Sake), and the preparation of [miso](https://en.wikipedia.org/wiki/Miso" \o "Miso), while *[Rhizopus](https://en.wikipedia.org/wiki/Rhizopus" \o "Rhizopus)* species are used for making [tempeh](https://en.wikipedia.org/wiki/Tempeh" \o "Tempeh). Several of these fungi are [domesticated](https://en.wikipedia.org/wiki/Domestication) species that were [bred](https://en.wikipedia.org/wiki/Breeding_program) or selected according to their capacity to ferment food without producing harmful mycotoxins (see below), which are produced by very closely related *[Aspergilli](https://en.wikipedia.org/wiki/Aspergillus_flavus" \o "Aspergillus flavus)*. [Quorn](https://en.wikipedia.org/wiki/Quorn_(food_product)" \o "Quorn (food product)), a [meat substitute](https://en.wikipedia.org/wiki/Meat_analogue), is made from *[Fusarium venenatum](https://en.wikipedia.org/wiki/Fusarium_venenatum" \o "Fusarium venenatum)*.

### Edible and poisonous species.:[Edible mushrooms](https://en.wikipedia.org/wiki/Edible_mushroom" \o "Edible mushroom) are well-known examples of fungi. Many are commercially raised, but others must be harvested from the wild. *[Agaricus bisporus](https://en.wikipedia.org/wiki/Agaricus_bisporus" \o "Agaricus bisporus)*, sold as button mushrooms when small or Portobello mushrooms when larger, is a commonly eaten species, used in salads, soups, and many other dishes. Many Asian fungi are commercially grown and have increased in popularity in the West. They are often available fresh in [grocery stores](https://en.wikipedia.org/wiki/Grocery_store) and markets, including straw mushrooms (*[Volvariella volvacea](https://en.wikipedia.org/wiki/Volvariella_volvacea" \o "Volvariella volvacea)*), oyster mushrooms (*[Pleurotus ostreatus](https://en.wikipedia.org/wiki/Pleurotus_ostreatus" \o "Pleurotus ostreatus)*), shiitakes (*[Lentinula edodes](https://en.wikipedia.org/wiki/Lentinula_edodes" \o "Lentinula edodes)*), and [enokitake](https://en.wikipedia.org/wiki/Enokitake" \o "Enokitake) (*[Flammulina](https://en.wikipedia.org/wiki/Flammulina" \o "Flammulina)* spp.).

### There are many more mushroom species that are [harvested from the wild](https://en.wikipedia.org/wiki/Mushroom_hunting) for personal consumption or commercial sale. [Milk mushrooms](https://en.wikipedia.org/wiki/Lactarius_deliciosus), [morels](https://en.wikipedia.org/wiki/Morel), [chanterelles](https://en.wikipedia.org/wiki/Chanterelle), [truffles](https://en.wikipedia.org/wiki/Truffles), [black trumpets](https://en.wikipedia.org/wiki/Craterellus), and *porcini* mushrooms ([*Boletus edulis*](https://en.wikipedia.org/wiki/Boletus_edulis)) (also known as king boletes) demand a high price on the market. They are often used in gourmet dishes.

### Certain types of cheeses require inoculation of milk curds with fungal species that impart a unique flavor and texture to the cheese. Examples include the [blue](https://en.wikipedia.org/wiki/Blue_cheese) color in cheeses such as [Stilton](https://en.wikipedia.org/wiki/Stilton_cheese) or [Roquefort](https://en.wikipedia.org/wiki/Roquefort), which are made by inoculation with[*Penicillium roqueforti*](https://en.wikipedia.org/wiki/Penicillium_roqueforti). Molds used in cheese production are non-toxic and are thus safe for human consumption; however, mycotoxins (e.g., aflatoxins, [roquefortine C](https://en.wikipedia.org/wiki/Roquefortine_C" \o "Roquefortine C), patulin, or others) may accumulate because of growth of other fungi during cheese ripening or storage. (*Amanita muscaria* Many mushroom species are [poisonous](https://en.wikipedia.org/wiki/Mushroom_poisoning) to humans, with toxicities ranging from slight digestive problems or [allergic](https://en.wikipedia.org/wiki/Allergy) reactions as well as [hallucinations](https://en.wikipedia.org/wiki/Hallucination) to severe organ failures and death. Genera with mushrooms containing deadly toxins include[*Conocybe*](https://en.wikipedia.org/wiki/Conocybe), *[Galerina](https://en.wikipedia.org/wiki/Galerina" \o "Galerina)*, *[Lepiota](https://en.wikipedia.org/wiki/Lepiota" \o "Lepiota)*, and, the most infamous, [*Amanita*](https://en.wikipedia.org/wiki/Amanita). The latter genus includes the destroying angel *(*[*A. virosa*](https://en.wikipedia.org/wiki/Amanita_virosa)*)* and the death cap *(*[*A. phalloides*](https://en.wikipedia.org/wiki/Amanita_phalloides)*)*, the most common cause of deadly mushroom poisoning. The false morel (*[Gyromitra esculenta](https://en.wikipedia.org/wiki/Gyromitra_esculenta" \o "Gyromitra esculenta)*) is occasionally considered a delicacy when cooked, yet can be highly toxic when eaten raw. *[Tricholoma equestre](https://en.wikipedia.org/wiki/Tricholoma_equestre" \o "Tricholoma equestre)* was considered edible until it was implicated in serious poisonings causing[rhabdomyolysis](https://en.wikipedia.org/wiki/Rhabdomyolysis). [Fly agaric](https://en.wikipedia.org/wiki/Amanita_muscaria) mushrooms) also cause occasional non-fatal poisonings, mostly as a result of ingestion for its [hallucinogenic](https://en.wikipedia.org/wiki/Psychedelics,_dissociatives_and_deliriants) properties. Historically, fly agaric was used by different peoples in Europe and Asia and its present usage for religious or [shamanic](https://en.wikipedia.org/wiki/Shamanism) purposes is reported from some ethnic groups such as the [Koryak people](https://en.wikipedia.org/wiki/Koryaks" \o "Koryaks) of north-eastern [Siberia](https://en.wikipedia.org/wiki/Siberia" \o "Siberia).As it is difficult to accurately identify a safe mushroom without proper training and knowledge, it is often advised to assume that a wild mushroom is poisonous and not to consume it.

### Pest control :In agriculture, fungi may be useful if they actively compete for nutrients and space with [pathogenic](https://en.wikipedia.org/wiki/Pathogen) microorganisms such as bacteria or other fungi via the [competitive exclusion principle](https://en.wikipedia.org/wiki/Competitive_exclusion_principle), or if they are [parasites](https://en.wikipedia.org/wiki/Parasitism) of these pathogens. For example, certain species may be used to eliminate or suppress the growth of harmful plant pathogens, such as insects, [mites](https://en.wikipedia.org/wiki/Mites), [weeds](https://en.wikipedia.org/wiki/Weed" \o "Weed),[nematodes](https://en.wikipedia.org/wiki/Nematodes" \o "Nematodes), and other fungi that cause diseases of important [crop](https://en.wikipedia.org/wiki/Crop) plants. This has generated strong interest in practical applications that use these fungi in the [biological control](https://en.wikipedia.org/wiki/Biological_control) of these agricultural pests. [Entomopathogenic fungi](https://en.wikipedia.org/wiki/Entomopathogenic_fungi" \o "Entomopathogenic fungi) can be used as[biopesticides](https://en.wikipedia.org/wiki/Biopesticides), as they actively kill insects. Examples that have been used as [biological insecticides](https://en.wikipedia.org/wiki/Biological_insecticide) are *[Beauveria bassiana](https://en.wikipedia.org/wiki/Beauveria_bassiana" \o "Beauveria bassiana)*, *[Metarhizium](https://en.wikipedia.org/wiki/Metarhizium" \o "Metarhizium)* spp, *[Hirsutella](https://en.wikipedia.org/wiki/Hirsutella" \o "Hirsutella)* spp, *[Paecilomyces](https://en.wikipedia.org/wiki/Paecilomyces" \o "Paecilomyces)* (*Isaria*) spp, and *[Lecanicillium lecanii](https://en.wikipedia.org/wiki/Lecanicillium_lecanii" \o "Lecanicillium lecanii)*.[Endophytic](https://en.wikipedia.org/wiki/Endophytic) fungi of grasses of the genus *[Neotyphodium](https://en.wikipedia.org/wiki/Neotyphodium" \o "Neotyphodium)*, such as [*N. coenophialum*](https://en.wikipedia.org/wiki/Neotyphodium_coenophialum), produce alkaloids that are toxic to a range of invertebrate and vertebrate [herbivores](https://en.wikipedia.org/wiki/Herbivores). These alkaloids protect grass plants from [herbivory](https://en.wikipedia.org/wiki/Herbivory), but several endophyte alkaloids can poison grazing animals, such as cattle and sheep. Infecting cultivars of [pasture](https://en.wikipedia.org/wiki/Pasture) or [forage](https://en.wikipedia.org/wiki/Forage) grasses with *Neotyphodium*endophytes is one approach being used in [grass breeding](https://en.wikipedia.org/wiki/Plant_breeding) programs; the fungal strains are selected for producing only alkaloids that increase resistance to herbivores such as insects, while being non-toxic to livestock.

### Bioremediation : Certain fungi, in particular "white rot" fungi, can degrade [insecticides](https://en.wikipedia.org/wiki/Insecticide), [herbicides](https://en.wikipedia.org/wiki/Herbicide), [pentachlorophenol](https://en.wikipedia.org/wiki/Pentachlorophenol), [creosote](https://en.wikipedia.org/wiki/Creosote), [coal tars](https://en.wikipedia.org/wiki/Coal_tar), and heavy fuels and turn them into [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide), water, and basic elements.Fungi have been shown to [biomineralize](https://en.wikipedia.org/wiki/Biomineralization" \o "Biomineralization) [uranium](https://en.wikipedia.org/wiki/Uranium) [oxides](https://en.wikipedia.org/wiki/Oxide), suggesting they may have application in the bioremediation of radioactively polluted sites

### Model organisms :Several pivotal discoveries in biology were made by researchers using fungi as [model organisms](https://en.wikipedia.org/wiki/Model_organisms), that is, fungi that grow and sexually reproduce rapidly in the laboratory. For example, the [one gene-one enzyme hypothesis](https://en.wikipedia.org/wiki/One_gene-one_enzyme_hypothesis) was formulated by scientists using the bread mold *[Neurospora crassa](https://en.wikipedia.org/wiki/Neurospora_crassa" \o "Neurospora crassa)* to test their biochemical theories.Other important model fungi are *[Aspergillus nidulans](https://en.wikipedia.org/wiki/Aspergillus_nidulans" \o "Aspergillus nidulans)* and the yeasts *Saccaromyces cerevisiae* and *[Schizosaccharomyces pombe](https://en.wikipedia.org/wiki/Schizosaccharomyces_pombe" \o "Schizosaccharomyces pombe)*, each of which with a long history of use to investigate issues in eukaryotic [cell biology](https://en.wikipedia.org/wiki/Cell_biology) and [genetics](https://en.wikipedia.org/wiki/Genetics), such as [cell cycle](https://en.wikipedia.org/wiki/Cell_cycle) regulation, [chromatin](https://en.wikipedia.org/wiki/Chromatin) structure, and [gene regulation](https://en.wikipedia.org/wiki/Gene_regulation). Other fungal models have more recently emerged that each address specific biological questions relevant to [medicine](https://en.wikipedia.org/wiki/Medicine), [plant pathology](https://en.wikipedia.org/wiki/Plant_pathology), and industrial uses; examples include[*Candida albicans*](https://en.wikipedia.org/wiki/Candida_albicans), a dimorphic, opportunistic human pathogen,[*Magnaporthe grisea*](https://en.wikipedia.org/wiki/Magnaporthe_grisea), a plant pathogen, and *[Pichia pastoris](https://en.wikipedia.org/wiki/Pichia_pastoris" \o "Pichia pastoris)*, a yeast widely used for eukaryotic[protein production](https://en.wikipedia.org/wiki/Protein_production).

### Others : Fungi are used extensively to produce industrial chemicals like [citric](https://en.wikipedia.org/wiki/Citric_acid), [gluconic](https://en.wikipedia.org/wiki/Gluconic_acid" \o "Gluconic acid), [lactic](https://en.wikipedia.org/wiki/Lactic_acid), and [malic](https://en.wikipedia.org/wiki/Malic_acid" \o "Malic acid) acids, and industrial enzymes, such as [lipases](https://en.wikipedia.org/wiki/Lipase) used in [biological detergents](https://en.wikipedia.org/wiki/Biological_detergent),[cellulases](https://en.wikipedia.org/wiki/Cellulase) used in making [cellulosic ethanol](https://en.wikipedia.org/wiki/Cellulosic_ethanol) and [stonewashed jeans](https://en.wikipedia.org/wiki/Stonewashed_jeans), and [amylases](https://en.wikipedia.org/wiki/Amylase),[invertases](https://en.wikipedia.org/wiki/Invertase), [proteases](https://en.wikipedia.org/wiki/Protease) and [xylanases](https://en.wikipedia.org/wiki/Xylanase" \o "Xylanase). Several species, most notably [*Psilocybin mushrooms*](https://en.wikipedia.org/wiki/Psilocybin_mushroom) (colloquially known as *magic mushrooms*), are ingested for their [psychedelic](https://en.wikipedia.org/wiki/Psychedelic_drug) properties, both [recreationally](https://en.wikipedia.org/wiki/Recreational_drug) and religiously.

## See also

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| [Portal icon](https://en.wikipedia.org/wiki/File:Karl_Johanssvamp,_Iduns_kokbok.png) | [***Fungi portal***](https://en.wikipedia.org/wiki/Portal:Fungi) |

* [Conservation of fungi](https://en.wikipedia.org/wiki/Conservation_of_fungi)
* [Fungal infection in animals](https://en.wikipedia.org/wiki/Fungal_infection_in_animals)
* [Fungal infection in plants](https://en.wikipedia.org/wiki/Fungal_infection_in_plants)
* [Marine fungi](https://en.wikipedia.org/wiki/Marine_fungi)
* [MycoBank](https://en.wikipedia.org/wiki/MycoBank)