



Fungus

A **fungus** (pl.: fungi^[e] or funguses^[6]) is any member of the group of eukaryotic organisms that includes microorganisms such as yeasts and molds, as well as the more familiar mushrooms. These organisms are classified as one of the traditional eukaryotic kingdoms, along with Animalia, Plantae, and either Protista^[7] or Protozoa and Chromista.^[8]

A characteristic that places fungi in a different kingdom from plants, bacteria, and some protists is chitin in their cell walls. Fungi, like animals, are heterotrophs; they acquire their food by absorbing dissolved organic molecules, typically by secreting digestive enzymes into their environment. Fungi do not photosynthesize. Growth is their means of mobility, except for spores (a few of which are flagellated), which may travel through the air or water. Fungi are the principal decomposers in ecological systems. These and other differences place fungi in a single group of related organisms, named the *Eumycota* (*true fungi* or *Eumycetes*), that share a common ancestor (i.e. they form a monophyletic group), an interpretation that is also strongly supported by molecular phylogenetics. This fungal group is distinct from the structurally similar myxomycetes (slime molds) and oomycetes (water molds). The discipline of biology devoted to the study of fungi is known as mycology (from the Greek μύκης, *mykes* 'mushroom'). In the past, mycology was regarded as a branch of botany, although it is now known that fungi are genetically more closely related to animals than to plants.

Abundant worldwide, most fungi are inconspicuous because of the small size of their structures, and their cryptic lifestyles in soil or on dead matter. Fungi include symbionts of plants, animals, or other fungi and also

Fungi

Temporal range: Middle Ordovician – Present (but see text)



Clockwise from top left:

[Amanita muscaria](#), a basidiomycete;

[Sarcoscypha coccinea](#), an ascomycete;

bread covered in mold;

a chytrid;

an [Aspergillus](#) conidiophore.

Scientific classification



Domain:	<u>Eukaryota</u>
Clade:	<u>Amorphea</u>
Clade:	<u>Obazoa</u>
Clade:	<u>Opisthokonta</u>
Clade:	<u>Holomycota</u>
Kingdom:	<u>Fungi</u>
	R.T.Moore (1980) ^{[1][2]}

Subkingdoms/phyla

- Rozellomyceta

- Rozellomycota

parasites. They may become noticeable when fruiting, either as mushrooms or as molds. Fungi perform an essential role in the decomposition of organic matter and have fundamental roles in nutrient cycling and exchange in the environment. They have long been used as a direct source of human food, in the form of mushrooms and truffles; as a leavening agent for bread; and in the fermentation of various food products, such as wine, beer, and soy sauce. Since the 1940s, fungi have been used for the production of antibiotics, and, more recently, various enzymes produced by fungi are used industrially and in detergents. Fungi are also used as biological pesticides to control weeds, plant diseases, and insect pests. Many species produce bioactive compounds called mycotoxins, such as alkaloids and polyketides, that are toxic to animals, including humans. The fruiting structures of a few species contain psychotropic compounds and are consumed recreationally or in traditional spiritual ceremonies. Fungi can break down manufactured materials and buildings, and become significant pathogens of humans and other animals. Losses of crops due to fungal diseases (e.g., rice blast disease) or food spoilage can have a large impact on human food supplies and local economies.

The fungus kingdom encompasses an enormous diversity of taxa with varied ecologies, life cycle strategies, and morphologies ranging from unicellular aquatic chytrids to large mushrooms. However, little is known of the true biodiversity of the fungus kingdom, which has been estimated at 2.2 million to 3.8 million species.^[9] Of these, only about 148,000 have been described,^[10] with over 8,000 species known to be detrimental to plants and at least 300 that can be pathogenic to humans.^[11] Ever since the pioneering 18th and 19th century taxonomical works of Carl Linnaeus, Christiaan Hendrik Persoon, and Elias Magnus Fries, fungi have been classified according to their morphology (e.g., characteristics such as spore color or microscopic features) or physiology. Advances

- Microsporidia
- Aphidiomyceta
 - Aphidiomycota
- "Eumycota"^[a]
 - Chytridiomyceta
 - Neocallimastigomycota
 - Monoblepharomycota
 - Chytridiomycota
 - Blastocladiomyceta
 - Blastocladiomycota
 - Sanchytriomycota^{[4][3]}
 - Amastigomycota
 - Basidiobolomyceta
 - Basidiobolomycota
 - Olpidiomyceta
 - Olpidiomycota
 - Zoopagomyceta
 - Zoopagomycota
 - Entomophthoromycota
 - Kickxellomycota
 - Mortierellomyceta
 - Mortierellomycota
 - Mucoromyceta (possibly paraphyletic)^[5]
 - Calcarisporiellomycota
 - Mucoromycota
 - Mortierellomycota^[b]
 - Glomeromycota^[c]
 - Dikarya
 - Entorrhizomycota
 - Basidiomycota
 - Ascomycota

in molecular genetics have opened the way for DNA analysis to be incorporated into taxonomy, which has sometimes challenged the historical groupings based on morphology and other traits. Phylogenetic studies published in the first decade of the 21st century have helped reshape the classification within the fungi kingdom, which is divided into one subkingdom, seven phyla, and ten subphyla.

Etymology

The English word *fungus* is directly adopted from the Latin *fungus* 'mushroom', used in the writings of Horace and Pliny.^[12] This in turn is derived from the Greek word *sphongos* (σφόγγος 'sponge'), which refers to the macroscopic structures and morphology of mushrooms and molds;^[13] the root is also used in other languages, such as the German *Schwamm* 'sponge' and *Schimmel* 'mold'.^[14]

The word *mycology* is derived from the Greek *mykes* (μύκης 'mushroom') and *logos* (λόγος 'discourse').^[15] It denotes the scientific study of fungi. The Latin adjectival form of "mycology" (*mycologicæ*) appeared as early as 1796 in a book on the subject by Christiaan Hendrik Persoon.^[16] The word appeared in English as early as 1824 in a book by Robert Kaye Greville.^[17] In 1836 the English naturalist Miles Joseph Berkeley's publication *The English Flora of Sir James Edward Smith, Vol. 5.* also refers to mycology as the study of fungi.^{[13][18]}

A group of all the fungi present in a particular region is known as *mycobiota* (plural noun, no singular).^[19] The term *mycota* is often used for this purpose, but many authors use it as a synonym of Fungi. The word *funga* has been proposed as a less ambiguous term morphologically similar to *fauna* and *flora*.^[20] The Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN) in August 2021 asked that the phrase *fauna and flora* be replaced by *fauna, flora, and funga*.^[21]

Characteristics

Before the introduction of molecular methods for phylogenetic analysis, taxonomists considered fungi to be members of the plant kingdom because of similarities in lifestyle: both fungi and plants are mainly immobile, and have similarities in general morphology and growth habit. Although inaccurate, the common misconception that fungi are plants persists among the general public due to their historical classification, as well as several similarities.^{[22][23]} Like plants, fungi often grow in soil and, in the case of mushrooms, form conspicuous fruit bodies, which sometimes resemble plants such as mosses. The fungi are now considered a separate kingdom, distinct from both plants and animals, from which they appear to have diverged around one billion years ago (around the start of the Neoproterozoic Era).^{[24][25]} 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: Fungal cells contain membrane-bound nuclei with chromosomes that contain DNA with noncoding regions called introns and coding regions called exons. Fungi have membrane-bound cytoplasmic organelles such as mitochondria, sterol-containing membranes, and ribosomes of the 80S type.^[26] They have a characteristic range of soluble

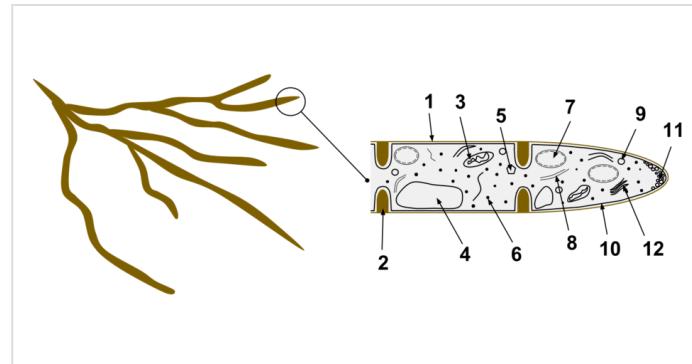
carbohydrates and storage compounds, including sugar alcohols (e.g., mannitol), disaccharides, (e.g., trehalose), and polysaccharides (e.g., glycogen, which is also found in animals^[27]).

- With animals: Fungi lack chloroplasts and are heterotrophic organisms and so require preformed organic compounds as energy sources.^[28]
- With plants: Fungi have a cell wall^[29] and vacuoles.^[30] They reproduce by both sexual and asexual means, and like basal plant groups (such as ferns and mosses) produce spores. Similar to mosses and algae, fungi typically have haploid nuclei.^[31]
- With euglenoids and bacteria: Higher fungi, euglenoids, and some bacteria produce the amino acid L-lysine in specific biosynthesis steps, called the α -amino adipate pathway.^{[32][33]}
- In common with some plant and animal species, more than one hundred fungal species display bioluminescence.^[34]

Unique features:

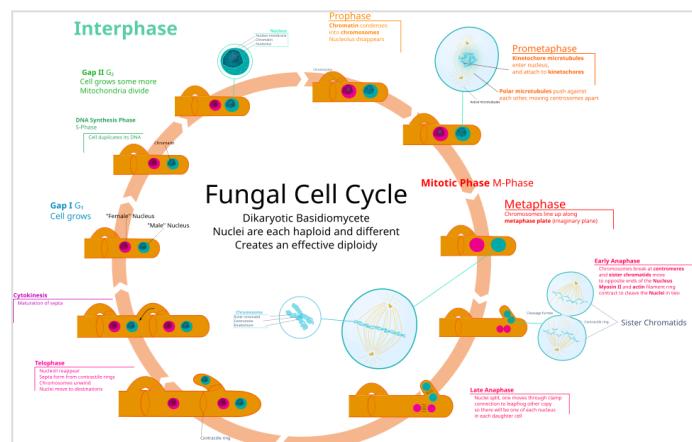
- The cells of most fungi grow as tubular, elongated, and thread-like (filamentous) structures called hyphae, which may contain multiple nuclei and extend by growing at their tips. Each tip contains a set of aggregated vesicles—cellular structures consisting of proteins, lipids, and other organic molecules—called the Spitzenkörper.^[35] Both fungi and oomycetes grow as filamentous hyphal cells.^[36] In contrast, similar-looking organisms, such as filamentous green algae, grow by repeated cell division within a chain of cells.^[27]
- Some species grow as unicellular yeasts that do not form hyphae and reproduce by budding or fission. Dimorphic fungi can switch between a yeast phase and a hyphal phase in response to environmental conditions.^[37]
- The fungal cell wall is made of a chitin-glucan complex; while glucans are also found in plants and chitin in the exoskeleton of arthropods,^[38] 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.^{[39][40]}

Most fungi lack an efficient system for the long-distance transport of water and nutrients, such as the xylem and phloem in many plants. To overcome this limitation, some fungi, such as Armillaria, form rhizomorphs,^[41] which resemble and perform functions similar to the roots of plants. As eukaryotes, fungi possess a biosynthetic pathway for producing terpenes that uses mevalonic acid and pyrophosphate as chemical building blocks.^[42] Plants and some other organisms have an additional terpene biosynthesis pathway in their chloroplasts, a structure that



Fungal hyphae cells

- | | |
|-----------------------|--------------------------|
| 1. Hyphal wall | 7. Nucleus |
| 2. Septum | 8. Endoplasmic reticulum |
| 3. Mitochondrion | 9. Lipid body |
| 4. Vacuole | 10. Plasma membrane |
| 5. Ergosterol crystal | 11. Spitzenkörper |
| 6. Ribosome | 12. Golgi apparatus |



Fungal cell cycle showing dikaryons typical of higher fungi

fungi and animals do not have.^[43] Fungi produce several secondary metabolites that are similar or identical in structure to those made by plants.^[42] Many of the plant and fungal enzymes that make these compounds differ from each other in sequence and other characteristics, which indicates separate origins and convergent evolution of these enzymes in the fungi and plants.^{[42][44]}



Omphalotus nidiformis, a bioluminescent mushroom

Diversity

Fungi have a worldwide distribution, and grow in a wide range of habitats, including extreme environments such as deserts or areas with high salt concentrations^[45] or ionizing radiation,^[46] as well as in deep sea sediments.^[47] Some can survive the intense UV and cosmic radiation encountered during space travel.^[48] Most grow in terrestrial environments, though several species live partly or solely in aquatic habitats, such as the chytrid fungi *Batrachochytrium dendrobatidis* and *B. salamandrivorans*, parasites that have been responsible for a worldwide decline in amphibian populations. These organisms spend part of their life cycle as a motile zoospore, enabling them to propel themselves through water and enter their amphibian host.^[49] Other examples of aquatic fungi include those living in hydrothermal areas of the ocean.^[50]



Bracket fungi on a tree stump



Widespread white fungus in wood chip mulch in an Oklahoma garden^[51]

As of 2020, around 148,000 species of fungi have been described by taxonomists,^[10] but the global biodiversity of the fungus kingdom is not fully understood.^[52] A 2017 estimate suggests there may be between 2.2 and 3.8 million species.^[9] The number of new fungi species discovered yearly has increased from 1,000 to 1,500 per year about 10 years ago, to about 2,000 with a peak of more than 2,500 species in 2016. In the year 2019, 1,882 new species of fungi were described, and it was estimated that more than 90% of fungi remain unknown.^[10] The following year, 2,905 new species were described—the highest annual record of new fungus names.^[53] In mycology, species have historically been distinguished by a

variety of methods and concepts. Classification based on morphological characteristics, such as the size and shape of spores or fruiting structures, has traditionally dominated fungal taxonomy.^[54] Species may also be distinguished by their biochemical and physiological characteristics, such as their ability to metabolize certain biochemicals, or their reaction to chemical tests. The biological species concept discriminates species based on their ability to mate. The application of molecular tools, such as DNA sequencing and phylogenetic analysis, to study diversity has greatly enhanced the resolution and added robustness to estimates of genetic diversity within various taxonomic groups.^[55]

Mycology

Mycology is the branch of 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 consumed for religious purposes, as well as their dangers, such as poisoning or infection. The field of phytopathology, the study of plant diseases, is closely related because many plant pathogens are fungi.^[56]

The use of fungi by humans dates back to prehistory; Ötzi the Iceman, a well-preserved mummy of a 5,300-year-old Neolithic man found frozen in the Austrian Alps, carried two species of polypore mushrooms that may have been used as tinder (*Fomes fomentarius*), or for medicinal purposes (*Piptoporus betulinus*).^[57] 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.^[58]



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

History

Mycology became a systematic science after the development of the microscope in the 17th century. Although fungal spores were first observed by Giambattista della Porta in 1588, the seminal work in the development of mycology is considered to be the publication of Pier Antonio Micheli's 1729 work *Nova plantarum genera*.^[59] 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.^[60] Extending the use of the binomial system of nomenclature introduced by Carl Linnaeus in his *Species plantarum* (1753), the Dutch Christiaan Hendrik Persoon (1761–1836) established the first classification of mushrooms with such skill as to be considered a founder of modern mycology. Later, Elias Magnus Fries (1794–1878) further elaborated the classification of fungi, using spore color and 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, August Carl Joseph Corda, Anton de Bary, the brothers Louis René and Charles Tulasne, Arthur H. R. Buller, Curtis G. Lloyd, and Pier Andrea Saccardo. In the 20th and 21st centuries, advances in biochemistry, genetics, molecular biology, biotechnology, DNA sequencing, and phylogenetic analysis have provided new insights into fungal relationships and biodiversity, and have challenged traditional morphology-based groupings in fungal taxonomy.^[61]

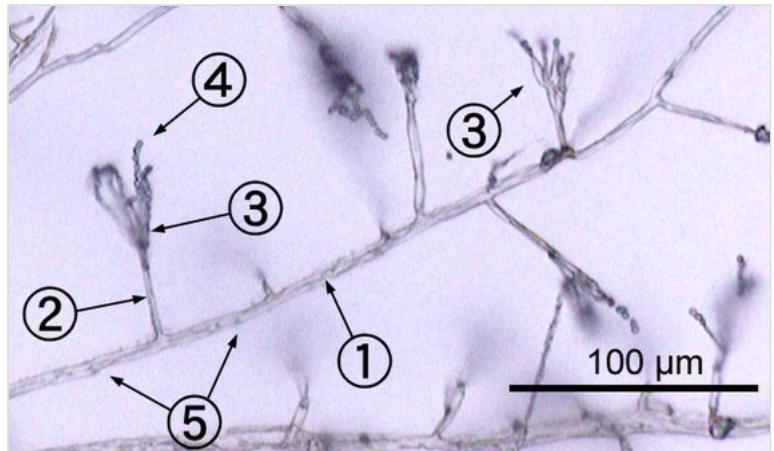
Morphology

Microscopic structures

Most fungi grow as hyphae, which are cylindrical, thread-like structures 2–10 μm 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.^[62] Hyphae also sometimes fuse when they come into contact, a process called *hyphal fusion* (or *anastomosis*). These growth processes lead to the development of a mycelium, an interconnected network of hyphae.^[37]

Hyphae can be either septate or

coenocytic. Septate hyphae are divided into compartments separated by cross walls (internal cell walls, called septa, that are formed at right angles to the cell wall giving the hypha its shape), with each compartment containing one or more nuclei; coenocytic hyphae are not compartmentalized.^[63] Septa have pores that allow cytoplasm, organelles, and sometimes nuclei to pass through; an example is the dolipore septum in fungi of the phylum Basidiomycota.^[64] Coenocytic hyphae are in essence multinucleate supercells.^[65]



An environmental isolate of *Penicillium*

- | | |
|------------------------|-------------------|
| 1. <u>Hypha</u> | 4. <u>Conidia</u> |
| 2. <u>Conidiophore</u> | 5. <u>Septa</u> |
| 3. <u>Phialide</u> | |

Many species have developed specialized hyphal structures for nutrient uptake from living hosts; examples include haustoria in plant-parasitic species of most fungal phyla,^[66] and arbuscules of several mycorrhizal fungi, which penetrate into the host cells to consume nutrients.^[67]

Although fungi are opisthokonts—a grouping of evolutionarily related organisms broadly characterized by a single posterior flagellum—all phyla except for the chytrids and blastocladiomycetes have lost their posterior flagella.^{[68][69]} Fungi are unusual among the eukaryotes in having a cell wall that, in addition to glucans (e.g., β -1,3-glucan) and other typical components, also contains the biopolymer chitin.^[40]

Macroscopic structures

Fungal mycelia can become visible to the naked eye, for example, on various surfaces and substrates, such as damp walls and spoiled food, where they are commonly called molds. Mycelia grown on solid agar media in laboratory petri dishes are usually referred to as colonies. These colonies can exhibit growth shapes and colors (due to spores or pigmentation) that can be used as diagnostic features in the identification of species or groups.^[70] Some individual fungal colonies

can reach extraordinary dimensions and ages as in the case of a clonal colony of *Armillaria solidipes*, which extends over an area of more than 900 ha (3.5 square miles), with an estimated age of nearly 9,000 years.^[71]

The apothecium—a specialized structure important in sexual reproduction in the ascomycetes—is a cup-shaped fruit body that is often macroscopic and holds the hymenium, a layer of tissue containing the spore-bearing cells.^[72] The fruit bodies of the basidiomycetes (basidiocarps) and some ascomycetes can sometimes grow very large, and many are well known as mushrooms.



Armillaria solidipes

Growth and physiology



Mold growth covering a decaying 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.^[73] Hyphae are specifically adapted for growth on solid surfaces, and to invade substrates and tissues.^[74] They can exert large penetrative mechanical forces; for example, many plant pathogens, including *Magnaporthe grisea*, form a structure called an appressorium that evolved to puncture plant tissues.^[75] The pressure generated by the appressorium, directed against the plant epidermis, can exceed 8 megapascals (1,200 psi).^[75] The filamentous fungus *Paecilomyces lilacinus* uses a similar structure to penetrate the eggs of nematodes.^[76]

The mechanical pressure exerted by the appressorium is generated from physiological processes that increase intracellular turgor by producing osmolytes such as glycerol.^[77] Adaptations such as these are complemented by hydrolytic enzymes secreted into the environment to digest large organic molecules—such as polysaccharides, proteins, and lipids—into smaller molecules that may then be absorbed as nutrients.^{[78][79][80]} The vast majority of filamentous fungi grow in a polar fashion (extending in one direction) by elongation at the tip (apex) of the hypha.^[81] 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 fungi,^[82] or growth by volume expansion during the development of mushroom stipes and other large organs.^[83] Growth of fungi as multicellular structures consisting of somatic and reproductive cells—a feature independently evolved in animals and plants^[84]—has several functions, including the development of fruit bodies for dissemination of sexual spores (see above) and biofilms for substrate colonization and intercellular communication.^[85]

Fungi are traditionally considered heterotrophs, organisms that rely solely on carbon fixed by other organisms for metabolism. Fungi have evolved 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, ammonia, acetate, or ethanol.^{[86][87]} In some species the pigment melanin may play a role in extracting energy from ionizing radiation, such as gamma radiation. This form of

"radiotrophic" growth has been described for only a few species, the effects on growth rates are small, and the underlying biophysical and biochemical processes are not well known.^[46] This process might bear similarity to CO₂ fixation via visible light, but instead uses ionizing radiation as a source of energy.^[88]

Reproduction

Fungal reproduction is complex, reflecting the differences in lifestyles and genetic makeup within this diverse kingdom of organisms.^[89] 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 of a species, the teleomorph (sexual reproduction) and the anamorph (asexual reproduction).^[90] 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.



Cerioporus squamosus

Asexual reproduction

Asexual reproduction occurs via vegetative spores (conidia) or through mycelial fragmentation. Mycelial fragmentation occurs when a fungal mycelium separates into pieces, and each component grows into a separate mycelium. Mycelial fragmentation and vegetative spores maintain clonal populations adapted to a specific niche, and allow more rapid dispersal than sexual reproduction.^[91] The "Fungi imperfecti" (fungi lacking the perfect or sexual stage) or Deuteromycota comprise all the species that lack an observable sexual cycle.^[92] Deuteromycota (alternatively known as Deuteromycetes, conidial fungi, or mitosporic fungi) is not an accepted taxonomic clade and is now taken to mean simply fungi that lack a known sexual stage.^[93]

Sexual reproduction

Sexual reproduction with meiosis has been directly observed in all fungal phyla except Glomeromycota^[94] (genetic analysis suggests meiosis in Glomeromycota as well). 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.^{[95][96]} Mating experiments between fungal isolates may identify species on the basis of biological species concepts.^[96] 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 and basidia, can be used in the identification of ascomycetes and basidiomycetes, respectively. Fungi employ two mating systems: heterothallic species allow mating only between individuals of the opposite mating type, whereas homothallic species can mate, and sexually reproduce, with any other individual or itself.^[97]

Most fungi have both a haploid and a 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, is required for the initiation of the sexual cycle. Many ascomycetes and basidiomycetes go through a 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).^[98]



The eight-spore asci of *Morchella elata*, viewed with phase-contrast microscopy

In ascomycetes, dikaryotic hyphae of the hymenium (the spore-bearing tissue layer) form a characteristic hook (crozier) at the hyphal septum. During cell division, the 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 (nuclear fusion) occurs. Asci are embedded in an ascocarp, or fruiting body. Karyogamy in the asci is followed immediately by meiosis and the production of ascospores. After dispersal, the ascospores may germinate and form a new haploid mycelium.^[99]

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, 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.^[100] A basidiocarp is formed in which club-like structures known as basidia generate haploid basidiospores after karyogamy and meiosis.^[101] The most commonly known basidiocarps are mushrooms, but they may also take other forms (see Morphology section).

In fungi formerly classified as Zygomycota, haploid hyphae of two individuals fuse, forming a gametangium, a specialized cell structure that becomes a fertile gamete-producing cell. The gametangium develops into a zygospore, a thick-walled spore formed by the union of gametes. When the zygospore germinates, it undergoes meiosis, generating new haploid hyphae, which may then form asexual sporangiospores. These sporangiospores allow the fungus to rapidly disperse and germinate into new genetically identical haploid fungal mycelia.^[102]

Spore dispersal

The spores of most of the researched species of fungi are transported by wind.^{[103][104]} Such species often produce dry or hydrophobic spores that do not absorb water and are readily scattered by raindrops, for example.^{[103][105][106]} In other species, 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.

Specialized mechanical and physiological mechanisms, as well as spore surface structures (such as hydrophobins), enable efficient spore ejection.^[107] For example, the structure of the spore-bearing cells in some ascomycete species is such that the buildup of substances affecting cell volume and fluid balance enables the explosive discharge of spores into the air.^[108] 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;^[109] 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.^[110] Other fungi, like the puffballs, rely on alternative mechanisms for spore release, such as external mechanical forces. The hydnoid fungi (tooth fungi) produce spores on pendant, tooth-like or spine-like projections.^[111] The bird's nest fungi use the force of falling water drops to liberate the spores from cup-shaped fruiting bodies.^[112] Another strategy is seen in the stinkhorns, a group of fungi with lively colors and putrid odor that attract insects to disperse their spores.^[113]



The bird's nest fungus *Cyathus stercoreus*

Homothallism

In homothallic sexual reproduction, two haploid nuclei derived from the same individual fuse to form a zygote that can then undergo meiosis. Homothallic fungi include species with an *Aspergillus*-like asexual stage (anamorphs) occurring in numerous different genera,^[114] several species of the ascomycete genus *Cochliobolus*,^[115] and the ascomycete *Pneumocystis jirovecii*.^[116] The earliest mode of sexual reproduction among eukaryotes was likely homothallism, that is, self-fertile unisexual reproduction.^[117]

Other sexual processes

Besides regular sexual reproduction with meiosis, certain fungi, such as those in the genera *Penicillium* and *Aspergillus*, may exchange genetic material via parasexual processes, initiated by anastomosis between hyphae and plasmogamy of fungal cells.^[118] 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^[119] and is likely required for hybridization between species, which has been associated with major events in fungal evolution.^[120]

Evolution

Fossil history

In contrast to plants and animals, 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, 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 fungi.^[121] Often recovered from a permineralized plant or animal host, these samples are typically studied by making thin-section preparations that can be examined with light microscopy or transmission electron microscopy.^[122] Researchers study compression fossils by dissolving the surrounding matrix with acid and then using light or scanning electron microscopy to examine surface details.^[123]

The earliest fossils possessing features typical of fungi date to the Paleoproterozoic era, some 2,400 million years ago (Ma); these multicellular benthic organisms had filamentous structures capable of anastomosis.^[124] Other 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.^[125] The oldest fossilized mycelium to be identified from its molecular composition is between 715 and 810 million years old.^[126] For much of the Paleozoic Era (542–251 Ma), the fungi appear to have been aquatic and consisted of organisms similar to the extant chytrids in having flagellum-bearing spores.^[127] The evolutionary adaptation from an aquatic to a terrestrial lifestyle necessitated a diversification of ecological strategies for obtaining nutrients, including parasitism, saprobism, and the development of mutualistic relationships such as mycorrhiza and lichenization.^[128] Studies suggest that the ancestral ecological state of the Ascomycota was saprobism, and that independent lichenization events have occurred multiple times.^[129]

In May 2019, scientists reported the discovery of a fossilized fungus, named *Ourasphaira giraldae*, in the Canadian Arctic, that may have grown on land a billion years ago, well before plants were living on land.^{[130][131][132]} Pyritized fungus-like microfossils preserved in the basal Ediacaran Doushantuo Formation (~635 Ma) have been reported in South China.^[133] Earlier, it had been presumed that the fungi colonized the land during the Cambrian (542–488.3 Ma), also long before land plants.^[134] Fossilized hyphae and spores recovered from the Ordovician of Wisconsin (460 Ma) resemble modern-day Glomerales, and existed at a time when the land flora likely consisted of only non-vascular bryophyte-like plants.^[135] Prototaxites, which was possibly a fungus or lichen, would have been the tallest organism of the late Silurian and early Devonian. Fungal fossils do not become common and uncontroversial until the early Devonian (416–359.2 Ma), when they occur abundantly in the Rhynie chert, mostly as Zygomycota and Chytridiomycota.^{[134][136][137]} At about this same time, approximately 400 Ma, the Ascomycota and Basidiomycota diverged,^[138] and all modern classes of fungi were present by the Late Carboniferous (Pennsylvanian, 318.1–299 Ma).^[139]

Lichens formed a component of the early terrestrial ecosystems, and the estimated age of the oldest terrestrial lichen fossil is 415 Ma;^[140] this date roughly corresponds to the age of the oldest known sporocarp fossil, a *Paleopyrenomycites* species found in the Rhynie Chert.^[141] The oldest fossil with microscopic features resembling modern-day basidiomycetes is *Palaeoancistrus*, found permineralized with a fern from the Pennsylvanian.^[142] Rare in the fossil record are the Homobasidiomycetes (a taxon roughly equivalent to the mushroom-producing species of the Agaricomycetes). Two amber-preserved specimens provide evidence that the earliest known mushroom-forming fungi (the extinct species *Archaeomarasmius leggerti*) appeared during the late Cretaceous, 90 Ma.^{[143][144]}

Some time after the Permian–Triassic extinction event (251.4 Ma), a fungal spike (originally thought to be an extraordinary abundance of fungal spores in sediments) formed, suggesting that fungi were the dominant life form at this time, representing nearly 100% of the available fossil record for this period.^[145] However, the relative proportion of fungal spores relative to spores formed by algal species is difficult to assess,^[146] the spike did not appear worldwide,^{[147][148]} and in many places it did not fall on the Permian–Triassic boundary.^[149]

Sixty-five million years ago, immediately after the Cretaceous–Paleogene extinction event that famously killed off most dinosaurs, there was a dramatic increase in evidence of fungi; apparently the death of most plant and animal species led to a huge fungal bloom like "a massive compost heap".^[150]

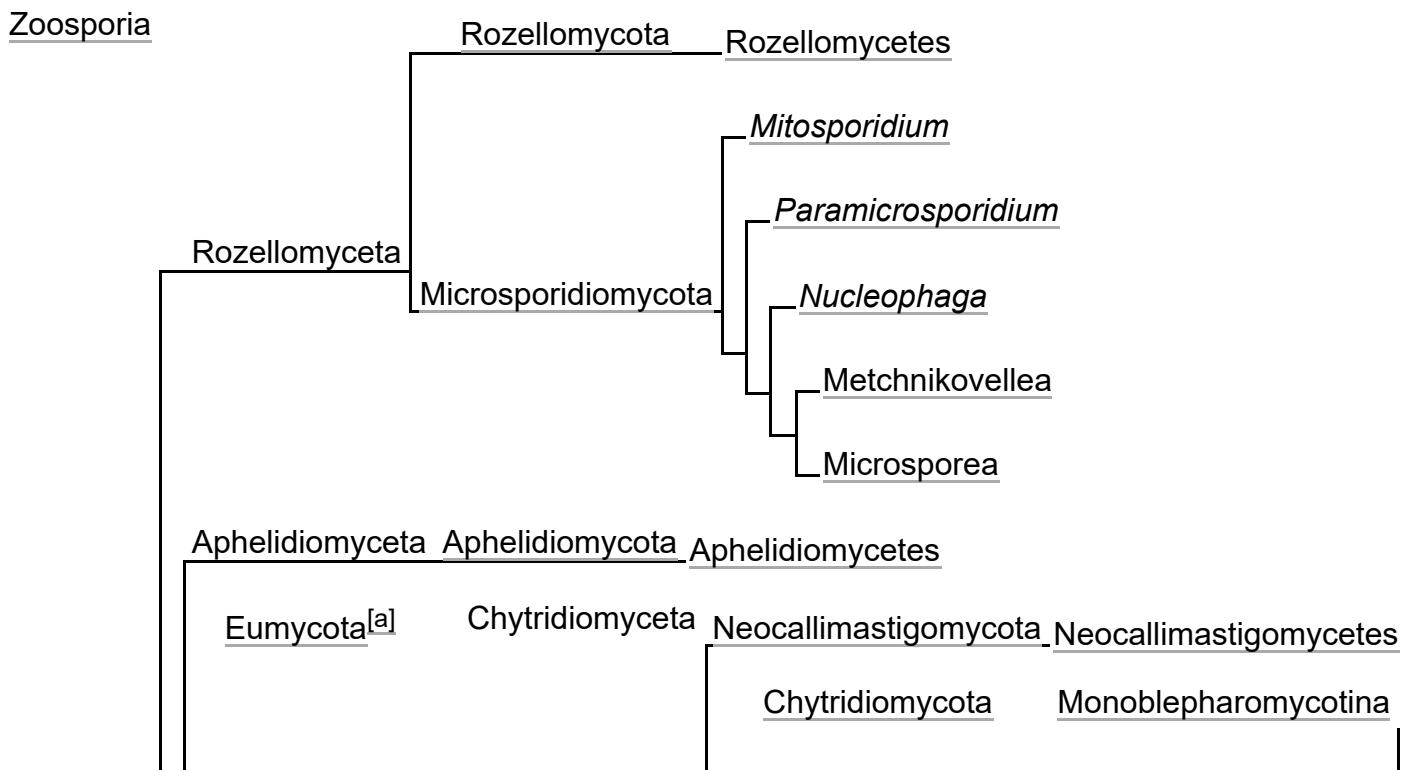
External phylogeny

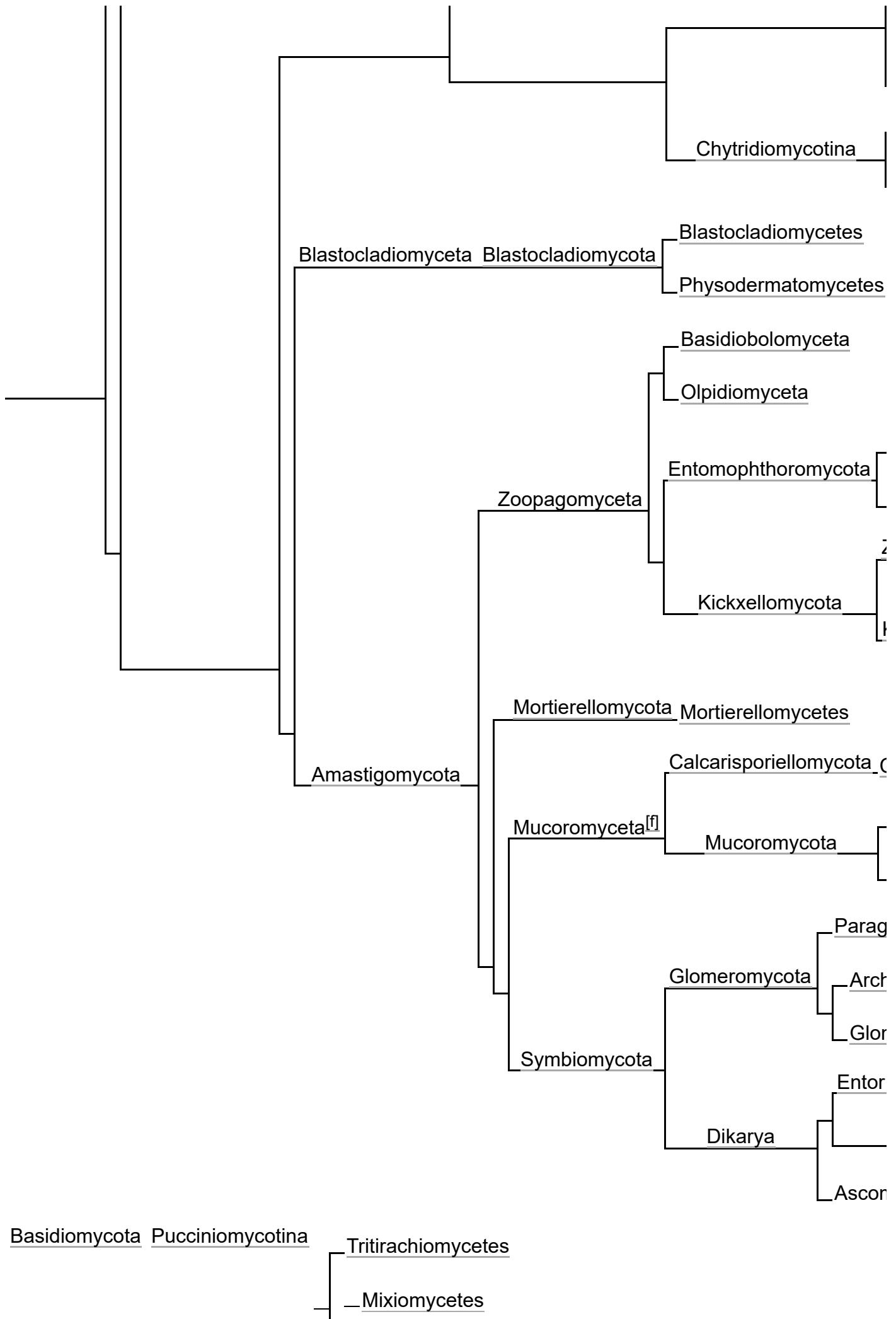
Although commonly included in botany curricula and textbooks, fungi are more closely related to animals than to plants, and are placed with the animals in the monophyletic group of opisthokonts.^[151] Analyses using molecular phylogenetics support a monophyletic origin of fungi.^{[55][152]} The taxonomy of fungi is in a state of constant flux, especially due to 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.^[153]

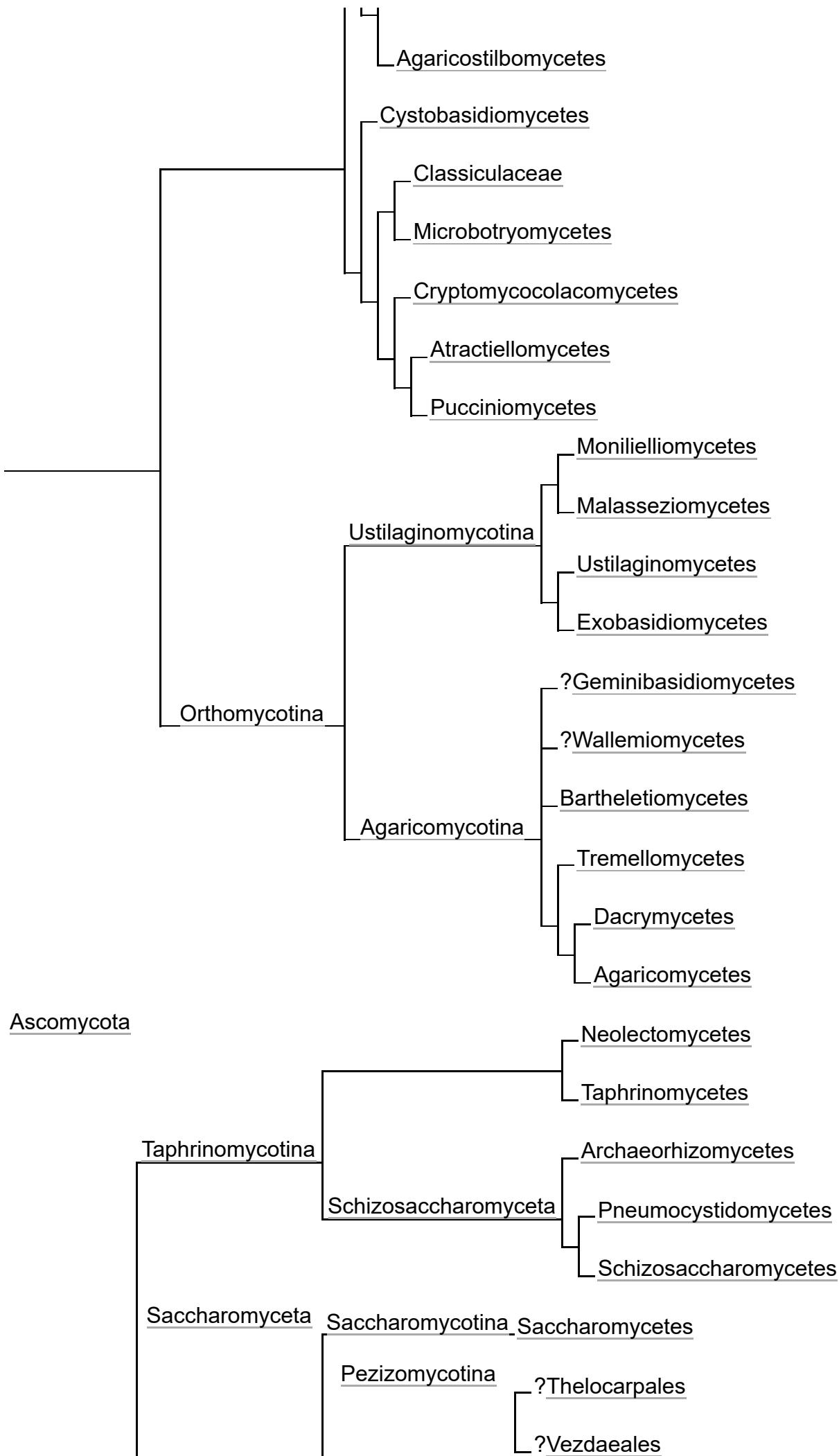
There is no unique generally accepted system at the higher taxonomic levels and there are frequent name changes at every level, from species upwards. Efforts among researchers are now underway to establish and encourage usage of a unified and more consistent nomenclature.^{[55][154]} Until relatively recent (2012) changes to the International Code of Nomenclature for algae, fungi and plants, fungal species could also have multiple scientific names depending on their life cycle and mode (sexual or asexual) of reproduction.^[155] Web sites such as Index Fungorum and MycoBank are officially recognized nomenclatural repositories and list current names of fungal species (with cross-references to older synonyms).^[156]

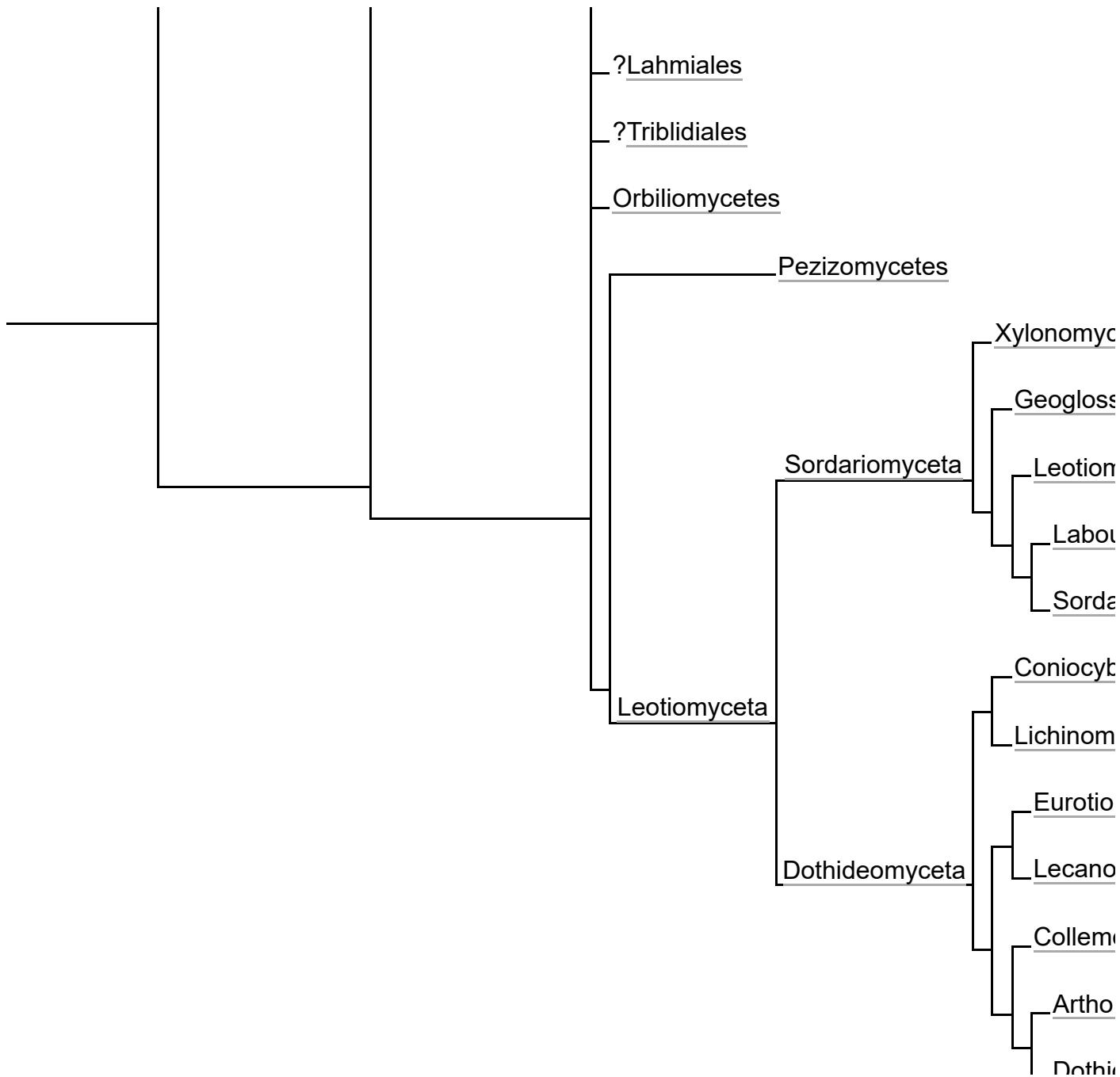
Internal phylogeny

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.^[55] It recognizes seven phyla, two of which—the Ascomycota and the Basidiomycota—are contained within a branch representing subkingdom Dikarya, the most species rich and familiar group, including all the mushrooms, most food-spoilage molds, most plant pathogenic fungi, and the beer, wine, and bread yeasts. The accompanying cladogram depicts the major fungal taxa and their relationship to opisthokont and unikont organisms, based on the work of Philippe Silar,^[157] "The Mycota: A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research"^[158] and Tedersoo et al. 2018.^[159] The lengths of the branches are not proportional to evolutionary distances.









Taxonomic groups

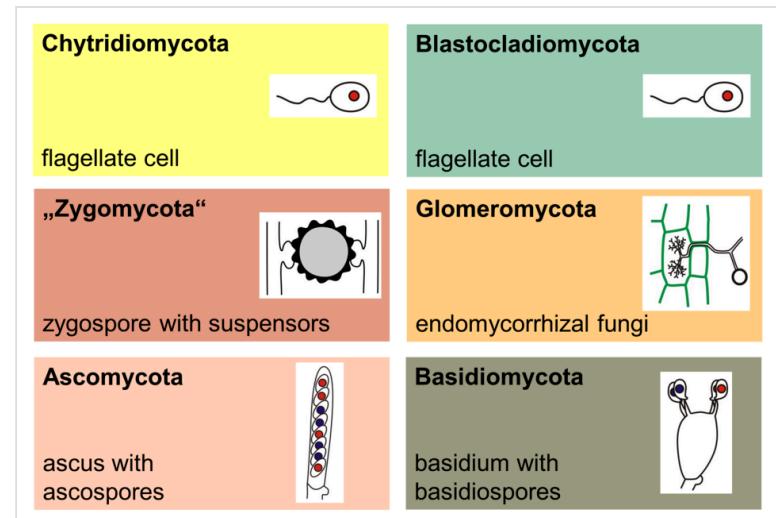
The major phyla (sometimes called divisions) of fungi have been classified mainly on the basis of characteristics of their sexual reproductive structures. As of 2019, nine major lineages have been identified: Opisthosporidia, Chytridiomycota, Neocallimastigomycota, Blastocladiomycota, Zoopagomycotina, Mucromycota, Glomeromycota, Ascomycota, and Basidiomycota.^[160]

Phylogenetic analysis has demonstrated that the Microsporidia, unicellular parasites of animals and protists, are fairly recent and highly derived endobiotic fungi (living within the tissue of another species).^[127] Previously considered to be "primitive" protozoa, they are now thought to be either a basal branch of the Fungi, or a sister group—each other's closest evolutionary relative.^[161]

The Chytridiomycota are commonly known as chytrids. These fungi are distributed worldwide. Chytrids and their close relatives Neocallimastigomycota and Blastocladiomycota (below) are the only fungi with active motility, producing zoospores that are capable of active movement through aqueous phases with a single flagellum, leading early taxonomists to classify them as protists.

Molecular phylogenies, inferred from rRNA sequences in ribosomes, suggest that the Chytrids are a basal group divergent from the other fungal phyla, consisting of four major clades with suggestive evidence for paraphyly or possibly polyphyly.^[162]

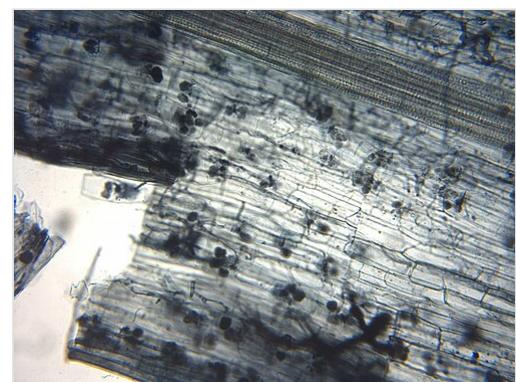
The Blastocladiomycota were previously considered a taxonomic clade within the Chytridiomycota. Molecular data and ultrastructural characteristics, however, place the Blastocladiomycota as a sister clade to the Zygomycota, Glomeromycota, and Dikarya (Ascomycota and Basidiomycota). The blastocladiomycetes are saprotrophs, 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, the blastocladiomycetes undergo sporic meiosis.^[127]



Main groups of fungi

The Neocallimastigomycota were earlier placed in the phylum Chytridiomycota. Members of this small phylum are anaerobic organisms, 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).^[163] They lack mitochondria but contain hydrogenosomes of mitochondrial origin. As in the related chytrids, neocallimastigomycetes form zoospores that are posteriorly uniflagellate or polyflagellate.^[55]

Members of the Glomeromycota form arbuscular mycorrhizae, a form of mutualist 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.^[94] The symbiotic association between the Glomeromycota and plants is ancient, with evidence dating to 400 million years ago.^[164] Formerly part of the Zygomycota (commonly known as 'sugar' and 'pin' molds), the Glomeromycota were elevated to phylum status in 2001 and now replace the older phylum Zygomycota.^[165] Fungi that were placed in the Zygomycota are now being reassigned to the Glomeromycota, or the subphyla incertae sedis Mucoromycotina, Kickxellomycotina, the Zoopagomycotina and the Entomophthoromycotina.^[55] Some well-known examples of fungi formerly in the Zygomycota include black bread mold (*Rhizopus stolonifer*), and *Pilobolus* species, capable of ejecting spores several meters through the air.^[166] Medically relevant genera include *Mucor*, *Rhizomucor*, and *Rhizopus*.^[167]



Arbuscular mycorrhiza seen under microscope. Flax root cortical cells containing paired arbuscules.

The Ascomycota, commonly known as sac fungi or ascomycetes, constitute the largest taxonomic group within the Eumycota.^[54] These fungi form meiotic spores called ascospores, which are enclosed in a special sac-like structure called an ascus. This phylum includes morels, a few

mushrooms and truffles, unicellular yeasts (e.g., of the genera *Saccharomyces*, *Kluyveromyces*, *Pichia*, and *Candida*), and many filamentous fungi living as saprotrophs, parasites, and mutualistic symbionts (e.g. lichens). Prominent and important genera of filamentous ascomycetes include *Aspergillus*, *Penicillium*, *Fusarium*, and *Claviceps*. Many ascomycete species have only been observed undergoing asexual reproduction (called anamorphic species), but analysis of molecular data has often been able to identify their closest teleomorphs in the Ascomycota.^[168] 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*).^[169]

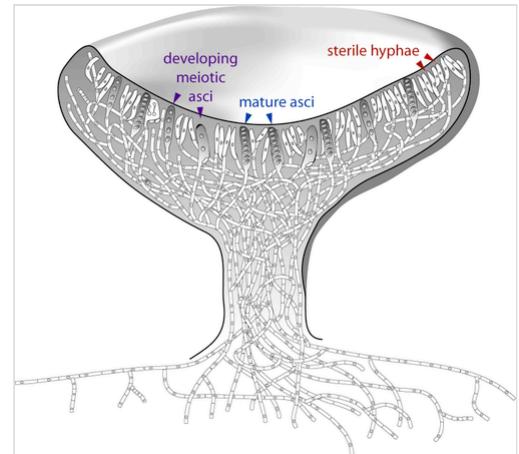


Diagram of an apothecium (the typical cup-like reproductive structure of ascomycetes) showing sterile tissues as well as developing and mature asci

Members of the Basidiomycota, commonly known as the club fungi or basidiomycetes, produce meiospores called basidiospores on club-like stalks called basidia. Most common mushrooms belong to this group, as well as rust and smut fungi, which are major pathogens of grains. Other important basidiomycetes include the maize pathogen *Ustilago maydis*,^[170] human commensal species of the genus *Malassezia*,^[171] and the opportunistic human pathogen, *Cryptococcus neoformans*.^[172]

Fungus-like organisms

Because of similarities in morphology and lifestyle, the slime molds (mycetozoans, plasmodiophorids, acrasids, *Fonticula*, and labyrinthulids, now in Amoebozoa, Rhizaria, Excavata, Cristidiscoidea, and Stramenopiles, respectively), water molds (oomycetes) and hyphochytrids (both Stramenopiles) were formerly classified in the kingdom Fungi, in groups like Mastigomycotina, Gymnomycota and Phycomycetes. The slime molds were studied also as protozoans, leading to an ambiregnal, duplicated taxonomy.^[173]

Unlike true fungi, the cell walls of oomycetes contain cellulose and lack 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 take in nutrients by ingestion (phagocytosis, except labyrinthulids) rather than absorption (osmotrophy, as fungi, labyrinthulids, oomycetes and hyphochytrids). Neither water molds nor slime molds are closely related to the true fungi, and, therefore, taxonomists no longer group them in the kingdom Fungi. Nonetheless, studies of the oomycetes and myxomycetes are still often included in mycology textbooks and primary research literature.^[174]

The Eccrinales and Amoebidiales are opisthokont protists, previously thought to be zygomycete fungi. Other groups now in Opisthokonta (e.g., *Corallochytrium*, *Ichthyosporea*) were also at given time classified as fungi. The genus *Blastocystis*, now in Stramenopiles, was originally classified as a yeast. *Ellobiopsis*, now in Alveolata, was considered a chytrid. The bacteria were also included in fungi in some classifications, as the group Schizomycetes.

The Rozellida clade, including the "ex-chytrid" *Rozella*, is a genetically disparate group known mostly from environmental DNA sequences that is a sister group to fungi.^[160] Members of the group that have been isolated lack the chitinous cell wall that is characteristic of fungi. Alternatively, *Rozella* can be classified as a basal fungal group.^[152]

The nucleariids may be the next sister group to the eumycete clade, and as such could be included in an expanded fungal kingdom.^[151] Many Actinomycetales (Actinomycetota), a group with many filamentous bacteria, were also long believed to be fungi.^{[175][176]}

Ecology

Although often inconspicuous, fungi occur in every environment on Earth and play very important roles in most ecosystems. Along with bacteria, fungi are the major decomposers in most terrestrial (and some aquatic) ecosystems, and therefore play a critical role in biogeochemical cycles^[177] and in many food webs. As decomposers, they play an essential role in nutrient cycling, especially as saprotrophs and symbionts, degrading organic matter to inorganic molecules, which can then re-enter anabolic metabolic pathways in plants or other organisms.^{[178][179]}



A pin mold decomposing a peach

Symbiosis

Many fungi have important symbiotic relationships with organisms from most if not all kingdoms.^{[180][181][182]} These interactions can be mutualistic or antagonistic in nature, or in the case of commensal fungi are of no apparent benefit or detriment to the host.^{[183][184][185]}

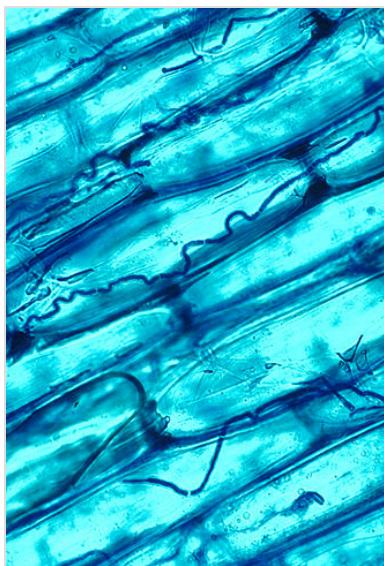
With plants

Mycorrhizal symbiosis between 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.^[186]

The mycorrhizal symbiosis is ancient, dating back to at least 400 million years.^[164] It often increases the plant's uptake of inorganic compounds, such as nitrate and phosphate from soils having low concentrations of these key plant nutrients.^{[178][187]} The fungal partners may also mediate plant-to-plant transfer of carbohydrates and other nutrients.^[188] Such mycorrhizal communities are called "common mycorrhizal networks".^{[189][190]} A special case of mycorrhiza is myco-heterotrophy, whereby the plant parasitizes the fungus, obtaining all of its nutrients from its fungal symbiont.^[191] Some fungal species inhabit the tissues inside roots, stems, and leaves, in which case they are called endophytes.^[192] 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.^[193]

With algae and cyanobacteria

Lichens are a symbiotic relationship between fungi and photosynthetic algae or cyanobacteria. The photosynthetic partner in the relationship is referred to in lichen terminology as a "photobiont". The fungal part of the relationship is composed mostly of various species of ascomycetes and a few basidiomycetes.^[194] Lichens occur in every ecosystem on all continents, play a key role in soil



The dark filaments are hyphae of the endophytic fungus *Epichloë coenophiala* in the intercellular spaces of tall fescue leaf sheath tissue

formation and the initiation of biological succession,^[195] and are prominent in some extreme environments, including polar, alpine, and semiarid desert regions.^[196] They are able to grow on inhospitable surfaces, including bare soil, rocks, tree bark, wood, shells, barnacles and leaves.^[197] As in mycorrhizas, the photobiont provides sugars and other carbohydrates via 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.^[198] Lichenization is a common mode of nutrition for



The lichen *Lobaria pulmonaria*, a symbiosis of fungal, algal, and cyanobacterial species

fungi; around 27% of known fungi—more than 19,400 species—are lichenized.^[199] Characteristics common to most lichens include obtaining organic carbon by photosynthesis, slow growth, small size, long life, long-lasting (seasonal) vegetative reproductive structures, mineral nutrition obtained largely from airborne sources, and greater tolerance of desiccation than most other photosynthetic organisms in the same habitat.^[200]

With insects

Many insects also engage in mutualistic relationships with fungi. Several groups of ants cultivate fungi in the order Chaetothyriales for several purposes: as a food source, as a structural component of their nests, and as a part of an ant/plant symbiosis in the domatia (tiny chambers in plants that house arthropods).^[201] Ambrosia beetles cultivate various species of fungi in the bark of trees that they infest.^[202] Likewise, females of several wood wasp species (genus *Sirex*) inject their eggs together with spores of the wood-rotting fungus *Amylostereum areolatum* into the sapwood of pine trees; the growth of the fungus provides ideal nutritional conditions for the development of the wasp larvae.^[203] At least one species of stingless bee has a relationship with a fungus in the genus *Monascus*, where the larvae consume and depend on fungus transferred from old to new nests.^[204] Termites on the African savannah are also known to cultivate fungi,^[180] and yeasts of the genera *Candida* and *Lachancea* inhabit the gut of a wide range of insects, including neuropterans, beetles, and cockroaches; it is not known whether these fungi benefit their hosts.^[205] Fungi growing in dead wood are essential for xylophagous insects (e.g. woodboring beetles).^{[206][207][208]} They deliver nutrients needed by xylophages to nutritionally scarce dead wood.^{[209][207][208]} Thanks to this nutritional enrichment the larvae of the woodboring insect is able to grow and develop to adulthood.^[206] The larvae of many families of fungicolous flies, particularly those within the superfamily Sciaroidea such as the Mycetophilidae and some Keroplatidae feed on fungal fruiting bodies and sterile mycorrhizae.^[210]

As parasites

Many fungi are parasites 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 fungus *Magnaporthe oryzae*,^[211] tree pathogens such as *Ophiostoma ulmi* and *Ophiostoma novo-ulmi* causing Dutch elm disease,^[212] *Cryphonectria parasitica* responsible for chestnut blight,^[213] and *Phymatotrichopsis omnivora* causing Texas Root Rot, and plant pathogens in the genera *Fusarium*, *Ustilago*, *Alternaria*, and *Cochliobolus*.^[184] Some carnivorous fungi, like *Paecilomyces lilacinus*, are predators of nematodes, which they capture using an array of specialized structures such as constricting rings or adhesive nets.^[214] Many fungi that are plant pathogens, such as *Magnaporthe oryzae*, can switch from being biotrophic (parasitic on living plants) to being necrotrophic (feeding on the dead tissues of plants they have killed).^[215] This same principle is applied to fungi-feeding parasites, including *Asterotremella albida*, which feeds on the fruit bodies of other fungi both while they are living and after they are dead.^[216]



Zombie ants, infected by the *Ophiocordyceps unilateralis* fungus, are predominantly found in tropical rainforests.

Some fungi alter the behavior of their animal hosts in ways that spread their spores more effectively (also called "active host transmission"). Examples include *Ophiocordyceps unilateralis* and possibly the extinct *Allocordyceps*.

As pathogens

Some fungi can cause serious diseases in humans, several of which may be fatal if untreated. These include aspergillosis, candidiasis, coccidioidomycosis, cryptococcosis, histoplasmosis, mycetomas, and paracoccidioidomycosis. Furthermore, a person with immunodeficiency is more susceptible to disease by genera such as *Aspergillus*, *Candida*, *Cryptococcus*,^{[185][217][218]} *Histoplasma*,^[219] and *Pneumocystis*.^[220] Other fungi can attack eyes, nails, hair, and especially skin, the so-called dermatophytic and keratinophilic fungi, and cause local infections such as ringworm and athlete's foot.^[221] Fungal spores are also a cause of allergies, and fungi from different taxonomic groups can evoke allergic reactions.^[222]



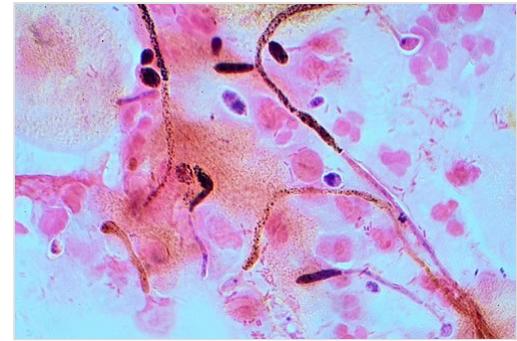
The plant pathogen *Puccinia magellanicum* (calafate rust) causes the defect known as witch's broom, seen here on a barberry shrub in Chile.

As targets of mycoparasites

Organisms that parasitize fungi are known as mycoparasitic organisms. About 300 species of fungi and fungus-like organisms, belonging to 13 classes and 113 genera, are used as biocontrol agents against plant fungal diseases.^[223] Fungi can also act as mycoparasites or antagonists of other fungi, such as *Hypomyces chrysospermus*, which grows on bolete mushrooms. Fungi can also become the target of infection by mycoviruses.^{[224][225]}

Communication

There appears to be electrical communication between fungi in word-like components according to spiking characteristics.^[226]



Gram stain of *Candida albicans* from a vaginal swab from a woman with candidiasis, showing hyphae, and chlamydospores, which are 2–4 μm in diameter

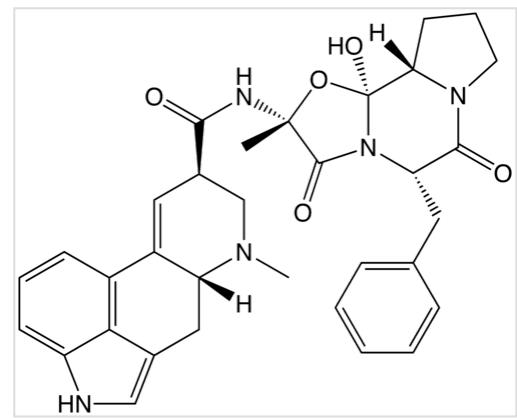
Possible impact on climate

According to a study published in the academic journal *Current Biology*, fungi can soak from the atmosphere around 36% of global fossil fuel greenhouse gas emissions.^{[227][228]}

Mycotoxins

Many fungi produce biologically active compounds, several of which are toxic to animals or plants and are therefore called 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 in some *Amanita* mushrooms, and ergot alkaloids, which have a long history of causing serious epidemics of ergotism (St Anthony's Fire) in people consuming rye or related cereals contaminated with sclerotia of the ergot fungus, *Claviceps purpurea*.^[229] Other notable mycotoxins include the aflatoxins, which are insidious liver toxins and highly carcinogenic metabolites produced by certain *Aspergillus* species often growing in or on grains and nuts consumed by humans, ochratoxins, patulin, and trichothecenes (e.g., T-2 mycotoxin) and fumonisins, which have significant impact on human food supplies or animal livestock.^[230]

Mycotoxins are secondary metabolites (or natural products), and research has established the existence of biochemical pathways solely for the purpose of producing mycotoxins and other natural products in fungi.^[42] Mycotoxins may provide fitness benefits in terms of physiological adaptation, competition with other microbes and fungi, and protection from consumption (fungivory).^{[231][232]} Many fungal secondary metabolites (or derivatives) are used medically, as described under Human use below.



Ergotamine, a major mycotoxin produced by *Claviceps* species, which if ingested can cause gangrene, convulsions, and hallucinations

Pathogenic mechanisms

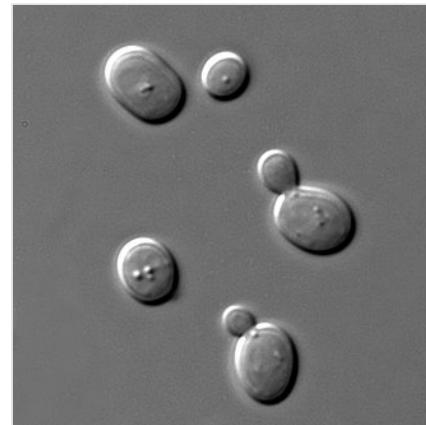
Ustilago maydis is a pathogenic plant fungus that causes smut disease in maize and teosinte. Plants have evolved efficient defense systems against pathogenic microbes such as *U. maydis*. A rapid defense reaction after pathogen attack is the oxidative burst where the plant produces reactive oxygen species 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*. The response protects *U. maydis* from the host defense, and is necessary for the pathogen's virulence.^[233]

Furthermore, *U. maydis* has a well-established recombinational DNA repair system which acts during mitosis and meiosis.^[234] The system may assist the pathogen in surviving DNA damage arising from the host plant's oxidative defensive response to infection.^[235]

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.^[236] Some *C. neoformans* can survive inside macrophages, which appears to be the basis for latency, 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.^[236] Another mechanism involves 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. The diploid nuclei of blastospores can undergo meiosis, including recombination, to form haploid basidiospores that can be dispersed.^[237] This process is referred to as monokaryotic fruiting. This process requires a gene called *DMC1*, which is a conserved homologue of genes *recA* in bacteria and *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.^{[235][237]}

Human use

The human use of fungi for food preparation or preservation and other purposes is extensive and has a long history. Mushroom farming and mushroom gathering are large industries in many countries. The study of the historical uses and sociological impact of fungi is known as ethnomycology. Because of the capacity of this group to produce an enormous range of natural products with antimicrobial or other biological activities, many species have long been used or are being developed for industrial production of antibiotics, vitamins, and anti-cancer and cholesterol-lowering drugs. Methods have been developed for genetic engineering of fungi,^[238] enabling metabolic engineering of fungal species. For example, genetic modification of yeast species^[239]—which are easy to grow at fast rates in large fermentation vessels—has opened up ways of pharmaceutical production that are potentially more efficient than production by the original source organisms.^[240] Fungi-based industries are sometimes considered to be a major part of a growing bioeconomy, with applications under research and development including use for textiles, meat substitution and general fungal biotechnology.^{[241][242][243][244][245]}



Saccharomyces cerevisiae cells shown with DIC microscopy

Therapeutic uses

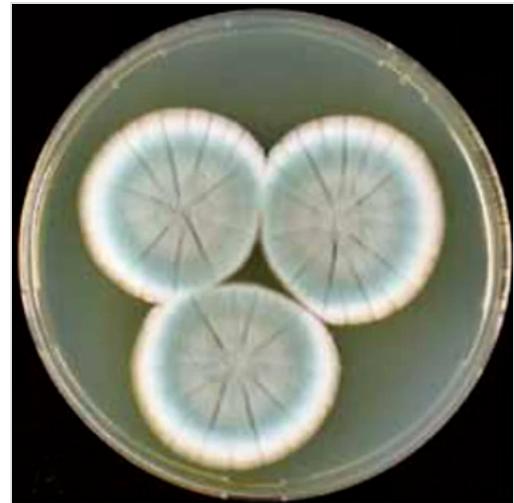
Modern chemotherapeutics

Many species produce metabolites that are major sources of pharmacologically active drugs.

Antibiotics

Particularly important are the antibiotics, including the penicillins, a structurally related group of β -lactam antibiotics that are synthesized from small peptides. Although naturally occurring penicillins such as penicillin G (produced by *Penicillium chrysogenum*) have a relatively narrow spectrum of biological activity, a wide range of other penicillins can be produced by chemical modification of the natural penicillins. Modern penicillins are semisynthetic compounds, obtained initially from fermentation cultures, but then structurally altered for specific desirable properties.^[247] Other antibiotics produced by fungi include: ciclosporin, commonly used as an immunosuppressant during transplant surgery; and fusidic acid, used to help control infection from methicillin-resistant *Staphylococcus aureus* bacteria.^[248]

Widespread use of antibiotics for the treatment of bacterial diseases, such as tuberculosis, syphilis, 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, and at low concentrations as quorum-sensing molecules for intra- or interspecies signaling.^[249]



The mold *Penicillium rubens* was the source of penicillin G.^[246]

Other

Other drugs produced by fungi include griseofulvin isolated from *Penicillium griseofulvum*, used to treat fungal infections,^[250] and statins (HMG-CoA reductase inhibitors), used to inhibit cholesterol synthesis. Examples of statins found in fungi include mevastatin from *Penicillium citrinum* and lovastatin from *Aspergillus terreus* and the oyster mushroom.^[251] Psilocybin from fungi is investigated for therapeutic use and appears to cause global increases in brain network integration.^[252] Fungi produce compounds that inhibit viruses^{[253][254]} and cancer cells.^[255] Specific metabolites, such as polysaccharide-K, ergotamine, and β -lactam antibiotics, are routinely used in clinical medicine. The shiitake mushroom is a source of lentinan, a clinical drug approved for use in cancer treatments in several countries, including Japan.^{[256][257]} In Europe and Japan, polysaccharide-K (brand name Krestin), a chemical derived from *Trametes versicolor*, is an approved adjuvant for cancer therapy.^[258]

Traditional medicine



The fungi *Ganoderma lucidum* (left) and *Ophiocordyceps sinensis* (right) are used in traditional medicine practices

Certain mushrooms are used as supposed therapeutics in folk medicine practices, such as traditional Chinese medicine. Mushrooms with a history of such use include *Agaricus subrufescens*,^{[255][259]} *Ganoderma lucidum*,^[260] and *Ophiocordyceps sinensis*.^[261]

Cultured foods

Baker's yeast or *Saccharomyces cerevisiae*, a unicellular fungus, is used to make bread and other wheat-based products, such as pizza dough and dumplings.^[262] Yeast species of the genus *Saccharomyces* are also used to produce alcoholic beverages through fermentation.^[263] Shoyu koji mold (*Aspergillus oryzae*) is an essential ingredient in brewing shoyu (soy sauce) and sake, and the preparation of miso,^[264] while *Rhizopus* species are used for making tempeh.^[265] Several of these fungi are domesticated species that were bred or selected according to their capacity to ferment food without producing harmful mycotoxins (see below), which are produced by very closely related *Aspergilli*.^[266] Quorn, a meat alternative, is made from *Fusarium venenatum*.^[267]

In food

Edible mushrooms include commercially raised and wild-harvested fungi. *Agaricus bisporus*, sold as button mushrooms when small or Portobello mushrooms when larger, is the most widely cultivated species in the West, 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 and markets, including straw mushrooms (*Volvariella volvacea*), oyster mushrooms (*Pleurotus ostreatus*), shiitakes (*Lentinula edodes*), and enokitake (*Flammulina* spp.).^[268]



A selection of edible Asian fungi

Many other mushroom species are harvested from the wild for personal consumption or commercial sale. Milk mushrooms, morels, chanterelles, truffles, black trumpets, and porcini mushrooms (*Boletus edulis*) (also known as king boletes) demand a high price on the market. They are often used in gourmet dishes.^[269]

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 color in cheeses such as Stilton or Roquefort, which are made by inoculation with *Penicillium roqueforti*.^[270] Molds used in cheese production are non-toxic and are thus safe for human consumption; however, mycotoxins (e.g., aflatoxins, roquefortine C, patulin, or others) may accumulate because of growth of other fungi during cheese ripening or storage.^[271]



Stilton cheese veined with *Penicillium roqueforti*

Poisonous fungi

Many mushroom species are poisonous to humans and cause a range of reactions including slight digestive problems, allergic reactions, hallucinations, severe organ failure, and death. Genera with mushrooms containing deadly toxins include *Conocybe*, *Galerina*, *Lepiota* and the most infamous, *Amanita*.^[272] The latter genus includes the destroying angel (*A. virosa*) and the death cap (*A. phalloides*), the most common cause of deadly mushroom poisoning.^[273] The false morel (*Gyromitra esculenta*) is occasionally considered a delicacy when cooked, yet can be highly toxic when eaten raw.^[274] *Tricholoma equestre* was considered edible until it was implicated in serious poisonings causing rhabdomyolysis.^[275] Fly agaric mushrooms (*Amanita muscaria*) also cause occasional non-fatal poisonings, mostly as a result of ingestion for its hallucinogenic properties. Historically, fly agaric was used by different peoples in Europe and Asia and its present usage for religious or shamanic purposes is reported from some ethnic groups such as the Koryak people of northeastern Siberia.^[276]



Amanita phalloides accounts for the majority of fatal mushroom poisonings worldwide. It sometimes lacks the greenish color seen here.

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.^{[277][278]}

Pest control



Grasshoppers killed by *Beauveria bassiana*

In agriculture, fungi may be useful if they actively compete for nutrients and space with pathogenic microorganisms such as bacteria or other fungi via the competitive exclusion principle,^[279] or if they are parasites of these pathogens. For example, certain species eliminate or suppress the growth of harmful plant pathogens, such as insects, mites, weeds, nematodes, and other fungi that cause diseases of important crop plants.^[280] This has generated strong interest in practical applications that use these fungi in the biological control of these agricultural pests. Entomopathogenic fungi can be used as biopesticides, as they actively kill insects.^[281] Examples that have been used as biological insecticides are *Beauveria bassiana*, *Metarhizium* spp., *Hirsutella* spp., *Paecilomyces* (*Isaria*) spp., and *Lecanicillium lecanii*.^{[282][283]}

Endophytic fungi of grasses of the genus *Epichloë*, such as *E. coenophiala*, produce alkaloids that are toxic to a range of invertebrate and vertebrate herbivores. These alkaloids protect grass plants from herbivory, but several endophyte alkaloids can poison grazing animals, such as cattle and sheep.^[284] Infecting cultivars of pasture or forage grasses with *Epichloë* endophytes is one approach being used in grass 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.^{[285][286]}

Bioremediation

Certain fungi, in particular white-rot fungi, can degrade insecticides, herbicides, pentachlorophenol, creosote, coal tars, and heavy fuels and turn them into carbon dioxide, water, and basic elements.^[287] Fungi have been shown to biomimic mineralize uranium oxides, suggesting they may have application in the bioremediation of radioactively polluted sites.^{[288][289][290]}

Model organisms

Several pivotal discoveries in biology were made by researchers using fungi as model organisms, that is, fungi that grow and sexually reproduce rapidly in the laboratory. For example, the one gene-one enzyme hypothesis was formulated by scientists using the bread mold *Neurospora crassa* to test their biochemical theories.^[291] Other important model fungi are *Aspergillus nidulans* and the yeasts *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe*, each of which with a long history of use to investigate issues in eukaryotic cell biology and genetics, such as cell cycle regulation, chromatin structure, and gene regulation. Other fungal models have emerged that address specific biological questions relevant to medicine, plant pathology, and industrial uses; examples include *Candida albicans*, a dimorphic, opportunistic human pathogen,^[292] *Magnaporthe grisea*, a plant pathogen,^[293] and *Pichia pastoris*, a yeast widely used for eukaryotic protein production.^[294]

Others

Fungi are used extensively to produce industrial chemicals like citric, gluconic, lactic, and malic acids,^[295] and industrial enzymes, such as lipases used in biological detergents,^[296] cellulases used in making cellulosic ethanol^[297] and stonewashed jeans,^[298] and amylases,^[299] invertases, proteases, and xylanases.^[300]

See also



[Fungi portal](#)

- [Conservation of fungi](#)
- [Fantastic Fungi](#)
- [Glossary of mycology](#)
- [Marine fungi](#)
- [Fungal infection](#)
- [Outline of fungi](#)
 - [Outline of lichens](#)
- [Fungi in art](#)

References

Footnotes

- a. This reflects a modern sense of "Eumycota", which is sister to Aphelinomycetida. It should be distinguished from the older sense used to separate fungi (now simply the kingdom "Fungi")

- from slime molds and water molds. The current "Eumycota" matches the protistologist's definition of Fungi as an exclusively osmotrophic lineage.^[3]
- b. Alternatively, included in Mucoromycota as a subphylum.
 - c. Alternatively, included in Mucoromycota as a subphylum. In rRNA-based analysis, groups with Dikarya to form Symbiomycota.
 - d. The first two pronunciations are favored more in the US and the others in the UK, however all pronunciations can be heard in any English-speaking country.
 - e. /'fʌndʒəɪ/ ⓘ, /'fʌŋgəɪ/ ⓘ, /'fʌŋgi/ ⓘ, or /'fʌndʒi/ ⓘ[d]
 - f. In protein-based analyses, Mucoromyceta is a clade that also includes Mortierellomycota and Glomeromycota.^[159]

Citations

1. Moore RT (1980). "Taxonomic proposals for the classification of marine yeasts and other yeast-like fungi including the smuts". *Botanica Marina*. **23** (6): 361–373. Bibcode:1980BoMar..23..361M (<https://ui.adsabs.harvard.edu/abs/1980BoMar..23..361M>). doi:10.1515/bot-1980-230605 (<https://doi.org/10.1515%2Fbot-1980-230605>).
2. "Record Details: Fungi R.T. Moore, Bot. Mar. 23(6): 371 (1980)" (<https://www.indexfungorum.org/Names/NamesRecord.asp?RecordID=90154>). Index Fungorum. Archived (<https://web.archive.org/web/20240618201249/https://www.indexfungorum.org/Names/NamesRecord.asp?RecordID=90154>) from the original on 18 June 2024. Retrieved 18 June 2024.
3. Hyde KD (2024). "The 2024 Outline of Fungi and fungus-like taxa". *Mycosphere*. **15** (1): 5146–6239. doi:10.5943/mycosphere/15/1/25 (<https://doi.org/10.5943%2Fmycosphere%2F15%2F1%2F25>). hdl:1854/LU-8660838 (<https://hdl.handle.net/1854%2FLU-8660838>).
4. Galindo LJ, López-García P, Torruella G, Karpov S, Moreira D (17 August 2021). "Phylogenomics of a new fungal phylum reveals multiple waves of reductive evolution across Holomycota" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8371127>). *Nature Communications*. **12** (1): 4973. Bibcode:2021NatCo..12.4973G (<https://ui.adsabs.harvard.edu/abs/2021NatCo..12.4973G>). doi:10.1038/s41467-021-25308-w (<https://doi.org/10.1038%2Fs41467-021-25308-w>). PMC 8371127 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8371127>). PMID 34404788 (<https://pubmed.ncbi.nlm.nih.gov/34404788>).
5. Wijayawardene NN, Hyde KD, Mikhailov KV, Péter G, Aptroot A, Pires-Zottarelli CL, et al. (15 October 2024). "Classes and phyla of the kingdom Fungi" (<https://doi.org/10.1007%2Fs13225-024-00540-z>). *Fungal Diversity*. **128** (1): 1–165. doi:10.1007/s13225-024-00540-z (<https://doi.org/10.1007%2Fs13225-024-00540-z>).
6. "Fungus" (<https://web.archive.org/web/20120728023308/http://oxforddictionaries.com/definition/english/fungus>). Oxford Dictionaries. Archived from the original (<http://oxforddictionaries.com/definition/english/fungus>) on 28 July 2012. Retrieved 26 February 2011.
7. Whittaker R (January 1969). "New concepts of kingdoms or organisms. Evolutionary relations are better represented by new classifications than by the traditional two kingdoms". *Science*. **163** (3863): 150–60. Bibcode:1969Sci...163..150W (<https://ui.adsabs.harvard.edu/abs/1969Sci...163..150W>). CiteSeerX 10.1.1.403.5430 (<https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.403.5430>). doi:10.1126/science.163.3863.150 (<https://doi.org/10.1126%2Fscience.163.3863.150>). PMID 5762760 (<https://pubmed.ncbi.nlm.nih.gov/5762760>).
8. Cavalier-Smith T (1998). "A revised six-kingdom system of life" (<http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=685>). *Biological Reviews*. **73** (3): 203–66. doi:10.1111/j.1469-185X.1998.tb00030.x (<https://doi.org/10.1111%2Fj.1469-185X.1998.tb00030.x>). PMID 9809012 (<https://pubmed.ncbi.nlm.nih.gov/9809012>). S2CID 6557779 (<https://api.semanticscholar.org/CorpusID:6557779>). Archived (<https://web.archive.org/web/20160820015246/http://journals.cambridge.org/action/displayAbstract?fromPage=online>) from the original on 20 August 2016. Retrieved 8 October 2023.

9. Hawksworth DL, Lücking R (July 2017). "Fungal Diversity Revisited: 2.2 to 3.8 Million Species" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11687528>). *Microbiology Spectrum*. **5** (4) 5.4.10: 79–95. doi:10.1128/microbiolspec.FUNK-0052-2016 (<https://doi.org/10.1128%2Fmicrobiolspec.FUNK-0052-2016>). ISBN 978-1-55581-957-6. PMC 11687528 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11687528>). PMID 28752818 (<https://pubmed.ncbi.nlm.nih.gov/28752818>).
10. Cheek M, Nic Lughadha E, Kirk P, Lindon H, Carretero J, Looney B, et al. (2020). "New scientific discoveries: Plants and fungi" (<https://doi.org/10.1002%2Fppp3.10148>). *Plants, People, Planet.* **2** (5): 371–388. Bibcode:2020PIPP...2..371C (<https://ui.adsabs.harvard.edu/abs/2020PIPP...2..371C>). doi:10.1002/ppp3.10148 (<https://doi.org/10.1002%2Fppp3.10148>). hdl:1854/LU-8705210 (<https://hdl.handle.net/1854%2FLU-8705210>).
11. "Stop neglecting fungi" (<https://doi.org/10.1038%2Fnmicrobiol.2017.120>). *Nature Microbiology*. **2** (8) 17120. 25 July 2017. doi:10.1038/nmicrobiol.2017.120 (<https://doi.org/10.1038%2Fnmicrobiol.2017.120>). PMID 28741610 (<https://pubmed.ncbi.nlm.nih.gov/28741610>).
12. Simpson DP (1979). *Cassell's Latin Dictionary* (5 ed.). London, UK: Cassell Ltd. p. 883. ISBN 978-0-304-52257-6.
13. Ainsworth 1976, p. 2.
14. Mitzka W, ed. (1960). *Etymologisches Wörterbuch der deutschen Sprache [Etymological dictionary of the German language]* (in German). Berlin: Walter de Gruyter.
15. Alexopoulos, Mims & Blackwell 1996, p. 1.
16. Persoon CH (1796). *Observationes Mycologicae: Part 1* (<https://web.archive.org/web/20131219091343/http://bibdigital.rjb.csic.es/ing/Libro.php?Libro=5680>) (in Latin). Leipzig, (Germany): Peter Philipp Wolf. Archived from the original (<http://bibdigital.rjb.csic.es/ing/Libro.php?Libro=5680>) on 19 December 2013. Retrieved 30 March 2019.
17. Greville RK (1824). *Scottish Cryptogamie Flora: Or Coloured Figures and Descriptions of Cryptogamic Plants, Belonging Chiefly to the Order Fungi* (<https://babel.hathitrust.org/cgi/pt?id=nyp.33433008943957;view=1up;seq=45>). Vol. 2. Edinburgh, Scotland: Maclachland and Stewart. p. 65. Archived (<https://web.archive.org/web/20190522230034/https://babel.hathitrust.org/cgi/pt?id=nyp.33433008943957;view=1up;seq=45>) from the original on 22 May 2019. Retrieved 30 March 2019. From p. 65: "This little plant will probably not prove rare in Great Britain, when mycology shall be more studied."
18. Smith JE (1836). Hooker WJ, Berkeley MJ (eds.). *The English Flora of Sir James Edward Smith* (<https://babel.hathitrust.org/cgi/pt?id=msu.31293010136830;view=1up;seq=403>). Vol. 5, part II: "Class XXIV. Cryptogamia". London, England: Longman, Rees, Orme, Brown, Green & Longman. p. 7. Archived (<https://web.archive.org/web/20200530032849/https://babel.hathitrust.org/cgi/pt?id=msu.31293010136830&view=1up&seq=403>) from the original on 30 May 2020. Retrieved 31 March 2019. From p. 7: "This has arisen, I conceive, partly from the practical difficulty of preserving specimens for the herbarium, partly from the absence of any general work, adapted to the immense advances which have of late years been made in the study of Mycology."
19. "LIAS Glossary" (<http://glossary.lias.net/wiki/Mycobiota>). Archived (<https://web.archive.org/web/20131211113036/http://glossary.lias.net/wiki/Mycobiota>) from the original on 11 December 2013. Retrieved 14 August 2013.
20. Kuhar F, Furci G, Drechsler-Santos ER, Pfister DH (2018). "Delimitation of Funga as a valid term for the diversity of fungal communities: the Fauna, Flora & Funga proposal (FF&F)" (<https://doi.org/10.1007%2FBF03449441>). *IMA Fungus*. **9** (2): A71 – A74. doi:10.1007/BF03449441 (<https://doi.org/10.1007%2FBF03449441>). hdl:11336/88035 (<https://hdl.handle.net/11336%2F88035>).

21. "IUCN SSC acceptance of Fauna Flora Funga" (<https://web.archive.org/web/20211111141833/https://www.iucn.org/sites/dev/files/statement-3f.pdf>) (PDF). Fungal Conservation Committee, IUCN SSC. 2021. Archived from the original (<https://www.iucn.org/sites/dev/files/statement-3f.pdf>) (PDF) on 11 November 2021. Retrieved 11 November 2021. "The IUCN Species Survival Commission calls for the due recognition of fungi as major components of biodiversity in legislation and policy. It fully endorses the Fauna Flora Funga Initiative and asks that the phrases **animals and plants** and **fauna and flora** be replaced with **animals, fungi, and plants** and **fauna, flora, and fungi**."
22. "Fifth-Grade Elementary School Students' Conceptions and Misconceptions about the Fungus Kingdom" (<https://www.researchgate.net/publication/26571382>). Retrieved 5 October 2022.
23. "Common Student Ideas about Plants and Animals" (https://www.cpp.edu/respect/resources/documents_kinder/pa_lessons_1-3/resources/gr0.kpa_common_student_ideas.pdf) (PDF). Archived (https://web.archive.org/web/20230326043113/https://www.cpp.edu/respect/resources/documents_kinder/pa_lessons_1-3/resources/gr0.kpa_common_student_ideas.pdf) (PDF) from the original on 26 March 2023. Retrieved 5 October 2022.
24. Bruns T (October 2006). "Evolutionary biology: a kingdom revised" (<https://doi.org/10.1038%2F443758a>). *Nature*. **443** (7113): 758–61. Bibcode:2006Natur.443..758B (<https://ui.adsabs.harvard.edu/abs/2006Natur.443..758B>). doi:10.1038/443758a (<https://doi.org/10.1038%2F443758a>). PMID 17051197 (<https://pubmed.ncbi.nlm.nih.gov/17051197>). S2CID 648881 (<https://api.semanticscholar.org/CorpusID:648881>).
25. Baldauf SL, Palmer JD (December 1993). "Animals and fungi are each other's closest relatives: congruent evidence from multiple proteins" (<https://doi.org/10.1073%2Fpnas.90.24.11558>). *Proceedings of the National Academy of Sciences of the United States of America*. **90** (24): 11558–62. Bibcode:1993PNAS...9011558B (<https://ui.adsabs.harvard.edu/abs/1993PNAS...9011558B>). doi:10.1073/pnas.90.24.11558 (<https://doi.org/10.1073%2Fpnas.90.24.11558>). PMC 48023 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC48023>). PMID 8265589 (<https://pubmed.ncbi.nlm.nih.gov/8265589>).
26. Deacon 2005, p. 4.
27. Deacon 2005, pp. 128–129.
28. Alexopoulos, Mims & Blackwell 1996, pp. 28–33.
29. Alexopoulos, Mims & Blackwell 1996, pp. 31–32.
30. Shoji JY, Arioka M, Kitamoto K (2006). "Possible involvement of pleiomorphic vacuolar networks in nutrient recycling in filamentous fungi" (<https://doi.org/10.4161%2Fauto.2695>). *Autophagy*. **2** (3): 226–7. doi:10.4161/auto.2695 (<https://doi.org/10.4161%2Fauto.2695>). PMID 16874107 (<https://pubmed.ncbi.nlm.nih.gov/16874107>).
31. Deacon 2005, p. 58.
32. Zabriskie TM, Jackson MD (February 2000). "Lysine biosynthesis and metabolism in fungi". *Natural Product Reports*. **17** (1): 85–97. doi:10.1039/a801345d (<https://doi.org/10.1039%2Fa801345d>). PMID 10714900 (<https://pubmed.ncbi.nlm.nih.gov/10714900>).
33. Xu H, Andi B, Qian J, West AH, Cook PF (2006). "The alpha-amino adipate pathway for lysine biosynthesis in fungi". *Cell Biochemistry and Biophysics*. **46** (1): 43–64. doi:10.1385/CBB:46:1:43 (<https://doi.org/10.1385%2FCBB%3A46%3A1%3A43>). PMID 16943623 (<https://pubmed.ncbi.nlm.nih.gov/16943623>). S2CID 22370361 (<https://api.semanticscholar.org/CorpusID:22370361>).
34. Desjardin DE, Perry BA, Lodge DJ, Stevani CV, Nagasawa E (2010). "Luminescent Mycena: new and noteworthy species" (<https://web.archive.org/web/20181111043819/http://www.producao.usp.br/handle/BDPI/16784>). *Mycologia*. **102** (2): 459–77. doi:10.3852/09-197 (<https://doi.org/10.3852%2F09-197>). PMID 20361513 (<https://pubmed.ncbi.nlm.nih.gov/20361513>). S2CID 25377671 (<https://api.semanticscholar.org/CorpusID:25377671>). Archived from the original (<http://producao.usp.br/handle/BDPI/16784>) on 11 November 2018. Retrieved 11 November 2018.
35. Alexopoulos, Mims & Blackwell 1996, pp. 27–28.
36. Alexopoulos, Mims & Blackwell 1996, p. 685.
37. Alexopoulos, Mims & Blackwell 1996, p. 30.

38. Alexopoulos, Mims & Blackwell 1996, pp. 32–33.
39. Alexopoulos, Mims & Blackwell 1996, p. 33.
40. Gow NA, Latge JP, Munro CA, Heitman J (2017). "The fungal cell wall: Structure, biosynthesis, and function" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11687499>). *Microbiology Spectrum*. **5** (3) 5.3.01. doi:10.1128/microbiolspec.FUNK-0035-2016 (<https://doi.org/10.1128%2Fmicrobiolspec.FUNK-0035-2016>). hdl:2164/8941 (<https://hdl.handle.net/2164%2F8941>). PMC 11687499 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11687499>). PMID 28513415 (<https://pubmed.ncbi.nlm.nih.gov/28513415>). S2CID 5026076 (<https://api.semanticscholar.org/CorpusID:5026076>).
41. Mihail JD, Bruhn JN (November 2005). "Foraging behaviour of *Armillaria* rhizomorph systems". *Mycological Research*. **109** (Pt 11): 1195–207. doi:10.1017/S0953756205003606 (<https://doi.org/10.1017%2FS0953756205003606>). PMID 16279413 (<https://pubmed.ncbi.nlm.nih.gov/16279413>).
42. Keller NP, Turner G, Bennett JW (December 2005). "Fungal secondary metabolism - from biochemistry to genomics". *Nature Reviews Microbiology*. **3** (12): 937–47. doi:10.1038/nrmicro1286 (<https://doi.org/10.1038%2Fnrmicro1286>). PMID 16322742 (<https://pubmed.ncbi.nlm.nih.gov/16322742>). S2CID 23537608 (<https://api.semanticscholar.org/CorpusID:23537608>).
43. Wu S, Schalk M, Clark A, Miles RB, Coates R, Chappell J (November 2006). "Redirection of cytosolic or plastidic isoprenoid precursors elevates terpene production in plants". *Nature Biotechnology*. **24** (11): 1441–7. doi:10.1038/nbt1251 (<https://doi.org/10.1038%2Fnbt1251>). PMID 17057703 (<https://pubmed.ncbi.nlm.nih.gov/17057703>). S2CID 23358348 (<https://api.semanticscholar.org/CorpusID:23358348>).
44. Tudzynski B (March 2005). "Gibberellin biosynthesis in fungi: genes, enzymes, evolution, and impact on biotechnology". *Applied Microbiology and Biotechnology*. **66** (6): 597–611. doi:10.1007/s00253-004-1805-1 (<https://doi.org/10.1007%2Fs00253-004-1805-1>). PMID 15578178 (<https://pubmed.ncbi.nlm.nih.gov/15578178>). S2CID 11191347 (<https://api.semanticscholar.org/CorpusID:11191347>).
45. Vaupotic T, Veranic P, Jenoe P, Plemenitas A (June 2008). "Mitochondrial mediation of environmental osmolytes discrimination during osmoadaptation in the extremely halotolerant black yeast *Hortaea werneckii*". *Fungal Genetics and Biology*. **45** (6): 994–1007. doi:10.1016/j.fgb.2008.01.006 (<https://doi.org/10.1016%2Fj.fgb.2008.01.006>). PMID 18343697 (<https://pubmed.ncbi.nlm.nih.gov/18343697>).
46. Dadachova E, Bryan RA, Huang X, Moadel T, Schweitzer AD, Aisen P, et al. (2007). "Ionizing radiation changes the electronic properties of melanin and enhances the growth of melanized fungi" (<https://doi.org/10.1371%2Fjournal.pone.0000457>). *PLOS ONE*. **2** (5) e457. Bibcode:2007PLoS...2..457D (<https://ui.adsabs.harvard.edu/abs/2007PLoS...2..457D>). doi:10.1371/journal.pone.0000457 (<https://doi.org/10.1371%2Fjournal.pone.0000457>). PMC 1866175 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1866175>). PMID 17520016 (<https://pubmed.ncbi.nlm.nih.gov/17520016>).
47. Raghukumar C, Raghukumar S (1998). "Barotolerance of fungi isolated from deep-sea sediments of the Indian Ocean" (<https://doi.org/10.3354%2Fame015153>). *Aquatic Microbial Ecology*. **15** (2): 153–163. doi:10.3354/ame015153 (<https://doi.org/10.3354%2Fame015153>).
48. Sancho LG, de la Torre R, Horneck G, Ascaso C, de Los Rios A, Pintado A, et al. (June 2007). "Lichens survive in space: results from the 2005 LICHENS experiment". *Astrobiology*. **7** (3): 443–54. Bibcode:2007AsBio...7..443S (<https://ui.adsabs.harvard.edu/abs/2007AsBio...7..443S>). doi:10.1089/ast.2006.0046 (<https://doi.org/10.1089%2Fast.2006.0046>). hdl:10261/20262 (<https://hdl.handle.net/10261%2F20262>). PMID 17630840 (<https://pubmed.ncbi.nlm.nih.gov/17630840>). S2CID 4121180 (<https://api.semanticscholar.org/CorpusID:4121180>).

49. Fisher MC, Garner TW (2020). "Chytrid fungi and global amphibian declines" (<https://discovery.ucl.ac.uk/id/eprint/10092667/>). *Nature Reviews Microbiology*. **18** (6): 332–343. doi:10.1038/s41579-020-0335-x (<https://doi.org/10.1038%2Fs41579-020-0335-x>). hdl:10044/1/78596 (<https://hdl.handle.net/10044%2F1%2F78596>). PMID 32099078 (<https://pubmed.ncbi.nlm.nih.gov/32099078>). S2CID 211266075 (<https://api.semanticscholar.org/CorpusID:211266075>). Archived (<https://web.archive.org/web/20220525144026/https://discovery.ucl.ac.uk/id/eprint/10092667/>) from the original on 25 May 2022. Retrieved 27 August 2021.
50. Vargas-Gastélum L, Riquelme M (2020). "The mycobiota of the deep sea: What omics can offer" (<https://doi.org/10.3390%2Flife10110292>). *Life*. **10** (11): 292. Bibcode:2020Life...10..292V (<https://ui.adsabs.harvard.edu/abs/2020Life...10..292V>). doi:10.3390/life10110292 (<https://doi.org/10.3390%2Flife10110292>). PMC 7699357 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7699357>). PMID 33228036 (<https://pubmed.ncbi.nlm.nih.gov/33228036>).
51. "Fungi in Mulches and Composts" (<https://ag.umass.edu/landscape/fact-sheets/fungi-in-mulches-composts>). University of Massachusetts Amherst. 6 March 2015. Archived (<https://web.archive.org/web/20221215220016/https://ag.umass.edu/landscape/fact-sheets/fungi-in-mulches-composts>) from the original on 15 December 2022. Retrieved 15 December 2022.
52. Mueller GM, Schmit JP (2006). "Fungal biodiversity: what do we know? What can we predict?". *Biodiversity and Conservation*. **16** (1): 1–5. doi:10.1007/s10531-006-9117-7 (<https://doi.org/10.1007%2Fs10531-006-9117-7>). S2CID 23827807 (<https://api.semanticscholar.org/CorpusID:23827807>).
53. Wang K, Cai L, Yao Y (2021). "Overview of nomenclature novelties of fungi in the world and China (2020)" (<https://doi.org/10.17520%2Fbiods.2021202>). *Biodiversity Science*. **29** (8): 1064–1072. doi:10.17520/biods.2021202 (<https://doi.org/10.17520%2Fbiods.2021202>). S2CID 240568551 (<https://api.semanticscholar.org/CorpusID:240568551>).
54. Kirk et al. 2008, p. 489.
55. Hibbett DS, Binder M, Bischoff JF, Blackwell M, Cannon PF, Eriksson OE, et al. (May 2007). "A higher-level phylogenetic classification of the Fungi" (<https://web.archive.org/web/20090326135053/http://www.clarku.edu/faculty/dhribbett/AFTOL/documents/AFTOL%20class%20mss%2023%2C%2024/AFTOL%20CLASS%20MS%20resub.pdf>) (PDF). *Mycological Research*. **111** (Pt 5): 509–47. CiteSeerX 10.1.1.626.9582 (<https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.626.9582>). doi:10.1016/j.mycres.2007.03.004 (<https://doi.org/10.1016%2Fj.mycres.2007.03.004>). PMID 17572334 (<https://pubmed.ncbi.nlm.nih.gov/17572334>). S2CID 4686378 (<https://api.semanticscholar.org/CorpusID:4686378>). Archived from the original (<http://www.clarku.edu/faculty/dhribbett/AFTOL/documents/AFTOL%20class%20mss%2023,%2024/AFTOL%20CLASS%20MS%20resub.pdf>) (PDF) on 26 March 2009. Retrieved 8 March 2007.
56. According to one 2001 estimate, some 10,000 fungal diseases are known. Struck C (2006). "Infection strategies of plant parasitic fungi". In Cooke BM, Jones DG, Kaye B (eds.). *The Epidemiology of Plant Diseases*. Berlin, Germany: Springer. p. 117. ISBN 978-1-4020-4580-6.
57. Peintner U, Pöder R, Pümpel T (1998). "The Iceman's fungi". *Mycological Research*. **102** (10): 1153–1162. doi:10.1017/S0953756298006546 (<https://doi.org/10.1017%2FS0953756298006546>).
58. Ainsworth 1976, p. 1.
59. Alexopoulos, Mims & Blackwell 1996, pp. 1–2.
60. Ainsworth 1976, p. 18.
61. Hawksworth DL (September 2006). "Pandora's mycological box: molecular sequences vs. morphology in understanding fungal relationships and biodiversity". *Revista Iberoamericana de Micología*. **23** (3): 127–33. doi:10.1016/S1130-1406(06)70031-6 (<https://doi.org/10.1016%2FS1130-1406%2806%2970031-6>). PMID 17196017 (<https://pubmed.ncbi.nlm.nih.gov/17196017>).

62. Harris SD (2008). "Branching of fungal hyphae: regulation, mechanisms and comparison with other branching systems" (<http://www.cybertruffle.org.uk/cyberliber/59350/0100/006/0823.htm>). *Mycologia*. **100** (6): 823–32. doi:10.3852/08-177 (<https://doi.org/10.3852%2F08-177>). PMID 19202837 (<https://pubmed.ncbi.nlm.nih.gov/19202837/>). S2CID 2147525 (<https://api.semanticscholar.org/CorpusID:2147525>). Archived (<https://web.archive.org/web/20160412145515/http://www.cybertruffle.org.uk/cyberliber/59350/0100/006/0823.htm>) from the original on 12 April 2016. Retrieved 5 July 2011.
63. Deacon 2005, p. 51.
64. Deacon 2005, p. 57.
65. Chang S-T, Miles PG (2004). *Mushrooms: Cultivation, Nutritional Value, Medicinal Effect and Environmental Impact*. Boca Raton, Florida: CRC Press. ISBN 978-0-8493-1043-0.
66. Bozkurt TO, Kamoun S, Lennon-Duménil AM (2020). "The plant-pathogen haustorial interface at a glance" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7075074>). *Journal of Cell Science*. **133** (5) jcs237958. doi:10.1242/jcs.237958 (<https://doi.org/10.1242%2Fjcs.237958>). PMC 7075074 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7075074>). PMID 32132107 (<https://pubmed.ncbi.nlm.nih.gov/32132107/>).
67. Parniske M (October 2008). "Arbuscular mycorrhiza: the mother of plant root endosymbioses". *Nature Reviews. Microbiology*. **6** (10): 763–75. doi:10.1038/nrmicro1987 (<https://doi.org/10.1038%2Fnrmicro1987>). PMID 18794914 (<https://pubmed.ncbi.nlm.nih.gov/18794914/>). S2CID 5432120 (<https://api.semanticscholar.org/CorpusID:5432120>).
68. Spatafora JW, Chang Y, Benny GL, Lazarus K, Smith ME, Berbee ML, et al. (September 2016). "A phylum-level phylogenetic classification of zygomycete fungi based on genome-scale data" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078412>). *Mycologia*. **108** (5): 1028–1046. doi:10.3852/16-042 (<https://doi.org/10.3852%2F16-042>). ISSN 0027-5514 (<https://search.worldcat.org/issn/0027-5514>). PMC 6078412 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078412>). PMID 27738200 (<https://pubmed.ncbi.nlm.nih.gov/27738200>).
69. Steenkamp ET, Wright J, Baldauf SL (January 2006). "The protistan origins of animals and fungi" (<https://doi.org/10.1093/molbev%2Fmsj011>). *Molecular Biology and Evolution*. **23** (1): 93–106. doi:10.1093/molbev/msj011 (<https://doi.org/10.1093%2Fmolbev%2Fmsj011>). PMID 16151185 (<https://pubmed.ncbi.nlm.nih.gov/16151185>).
70. Hanson 2008, pp. 127–141.
71. Ferguson BA, Dreisbach TA, Parks CG, Filip GM, Schmitt CL (2003). "Coarse-scale population structure of pathogenic *Armillaria* species in a mixed-conifer forest in the Blue Mountains of northeast Oregon" (<https://zenodo.org/record/1235905>). *Canadian Journal of Forest Research*. **33** (4): 612–623. Bibcode:2003CaJFR..33..612F (<https://ui.adsabs.harvard.edu/abs/2003CaJFR..33..612F>). doi:10.1139/x03-065 (<https://doi.org/10.1139%2Fx03-065>). Archived (<https://web.archive.org/web/20190703164318/https://zenodo.org/record/1235905>) from the original on 3 July 2019. Retrieved 3 July 2019.
72. Alexopoulos, Mims & Blackwell 1996, pp. 204–205.
73. Moss ST (1986). *The Biology of Marine Fungi*. Cambridge, UK: Cambridge University Press. p. 76. ISBN 978-0-521-30899-1.
74. Peñalva MA, Arst HN (September 2002). "Regulation of gene expression by ambient pH in filamentous fungi and yeasts" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC120796>). *Microbiology and Molecular Biology Reviews*. **66** (3): 426–46, table of contents. doi:10.1128/MMBR.66.3.426-446.2002 (<https://doi.org/10.1128%2FMMBR.66.3.426-446.2002>). PMC 120796 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC120796>). PMID 12208998 (<https://pubmed.ncbi.nlm.nih.gov/12208998>).
75. Howard RJ, Ferrari MA, Roach DH, Money NP (December 1991). "Penetration of hard substrates by a fungus employing enormous turgor pressures" (<https://doi.org/10.1073%2Fpnas.88.24.11281>). *Proceedings of the National Academy of Sciences of the United States of America*. **88** (24): 11281–4. Bibcode:1991PNAS...8811281H (<https://ui.adsabs.harvard.edu/abs/1991PNAS...8811281H>). doi:10.1073/pnas.88.24.11281 (<https://doi.org/10.1073%2Fpnas.88.24.11281>). PMC 53118 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC53118>). PMID 1837147 (<https://pubmed.ncbi.nlm.nih.gov/1837147>).

76. Money NP (1998). "Mechanics of invasive fungal growth and the significance of turgor in plant infection". *Molecular Genetics of Host-Specific Toxins in Plant Disease: Proceedings of the 3rd Tottori International Symposium on Host-Specific Toxins, Daisen, Tottori, Japan, August 24–29, 1997*. Netherlands: Kluwer Academic Publishers. pp. 261–271. ISBN 978-0-7923-4981-5.
77. Wang ZY, Jenkinson JM, Holcombe LJ, Soanes DM, Veneault-Fourrey C, Bhambra GK, et al. (April 2005). "The molecular biology of appressorium turgor generation by the rice blast fungus *Magnaporthe grisea*". *Biochemical Society Transactions*. **33** (Pt 2): 384–8. doi:10.1042/BST0330384 (<https://doi.org/10.1042%2FBST0330384>). PMID 15787612 (<https://pubmed.ncbi.nlm.nih.gov/15787612/>). S2CID 7111935 (<https://api.semanticscholar.org/CorpusID:7111935>).
78. Pereira JL, Noronha EF, Miller RN, Franco OL (June 2007). "Novel insights in the use of hydrolytic enzymes secreted by fungi with biotechnological potential" (<https://doi.org/10.1111%2Fj.1472-765X.2007.02151.x>). *Letters in Applied Microbiology*. **44** (6): 573–81. doi:10.1111/j.1472-765X.2007.02151.x (<https://doi.org/10.1111%2Fj.1472-765X.2007.02151.x>). PMID 17576216 (<https://pubmed.ncbi.nlm.nih.gov/17576216>).
79. Schaller M, Borelli C, Kortring HC, Hube B (November 2005). "Hydrolytic enzymes as virulence factors of *Candida albicans*". *Mycoses*. **48** (6): 365–77. doi:10.1111/j.1439-0507.2005.01165.x (<https://doi.org/10.1111%2Fj.1439-0507.2005.01165.x>). PMID 16262871 (<https://pubmed.ncbi.nlm.nih.gov/16262871>). S2CID 1356254 (<https://api.semanticscholar.org/CorpusID:1356254>).
80. Farrar JF (October 1985). "Carbohydrate metabolism in biotrophic plant pathogens". *Microbiological Sciences*. **2** (10): 314–7. PMID 3939987 (<https://pubmed.ncbi.nlm.nih.gov/3939987>).
81. Fischer R, Zekert N, Takeshita N (May 2008). "Polarized growth in fungi--interplay between the cytoskeleton, positional markers and membrane domains". *Molecular Microbiology*. **68** (4): 813–26. doi:10.1111/j.1365-2958.2008.06193.x (<https://doi.org/10.1111%2Fj.1365-2958.2008.06193.x>). PMID 18399939 (<https://pubmed.ncbi.nlm.nih.gov/18399939>). S2CID 205365895 (<https://api.semanticscholar.org/CorpusID:205365895>).
82. Christensen MJ, Bennett RJ, Ansari HA, Koga H, Johnson RD, Bryan GT, et al. (February 2008). "Epichloë endophytes grow by intercalary hyphal extension in elongating grass leaves". *Fungal Genetics and Biology*. **45** (2): 84–93. doi:10.1016/j.fgb.2007.07.013 (<https://doi.org/10.1016/j.fgb.2007.07.013>). PMID 17919950 (<https://pubmed.ncbi.nlm.nih.gov/17919950>).
83. Money NP (October 2002). "Mushroom stem cells" (<https://doi.org/10.1002%2Fbies.10160>). *BioEssays*. **24** (10): 949–52. doi:10.1002/bies.10160 (<https://doi.org/10.1002%2Fbies.10160>). PMID 12325127 (<https://pubmed.ncbi.nlm.nih.gov/12325127>).
84. Willensdorfer M (February 2009). "On the evolution of differentiated multicellularity". *Evolution; International Journal of Organic Evolution*. **63** (2): 306–23. arXiv:0801.2610 (<https://arxiv.org/abs/0801.2610>). Bibcode:2009Evolu..63..306W (<https://ui.adsabs.harvard.edu/abs/2009Evolu..63..306W>). doi:10.1111/j.1558-5646.2008.00541.x (<https://doi.org/10.1111%2Fj.1558-5646.2008.00541.x>). PMID 19154376 (<https://pubmed.ncbi.nlm.nih.gov/19154376>). S2CID 39155292 (<https://api.semanticscholar.org/CorpusID:39155292>).
85. Daniels KJ, Srikantha T, Lockhart SR, Pujol C, Soll DR (May 2006). "Opaque cells signal white cells to form biofilms in *Candida albicans*" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1462973>). *The EMBO Journal*. **25** (10): 2240–52. doi:10.1038/sj.emboj.7601099 (<https://doi.org/10.1038/sj.emboj.7601099>). PMC 1462973 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1462973>). PMID 16628217 (<https://pubmed.ncbi.nlm.nih.gov/16628217>).
86. Tudzynski B (2014). "Nitrogen regulation of fungal secondary metabolism in fungi" (<https://doi.org/10.3389%2Ffmicb.2014.00656>). *Frontiers in Microbiology*. **5**: 656. doi:10.3389/fmicb.2014.00656 (<https://doi.org/10.3389%2Ffmicb.2014.00656>). PMC 4246892 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4246892>). PMID 25506342 (<https://pubmed.ncbi.nlm.nih.gov/25506342>).
87. Hynes MJ (1994). "Regulatory circuits of the amdS gene of *Aspergillus nidulans*". *Antonie van Leeuwenhoek*. **65** (3): 179–82. doi:10.1007/BF00871944 (<https://doi.org/10.1007%2FBF00871944>). PMID 7847883 (<https://pubmed.ncbi.nlm.nih.gov/7847883>). S2CID 45815733 (<https://api.semanticscholar.org/CorpusID:45815733>).

88. Dadachova E, Casadevall A (December 2008). "Ionizing radiation: how fungi cope, adapt, and exploit with the help of melanin" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2677413>). *Current Opinion in Microbiology*. **11** (6): 525–31. doi:10.1016/j.mib.2008.09.013 (<https://doi.org/10.1016%2Fj.mib.2008.09.013>). PMC 2677413 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2677413>). PMID 18848901 (<https://pubmed.ncbi.nlm.nih.gov/18848901>).
89. Alexopoulos, Mims & Blackwell 1996, pp. 48–56.
90. Kirk et al. 2008, p. 633.
91. Heitman J (September 2006). "Sexual reproduction and the evolution of microbial pathogens" (<https://doi.org/10.1016%2Fj.cub.2006.07.064>). *Current Biology*. **16** (17): R711–25. Bibcode:2006CBio...16.R711H (<https://ui.adsabs.harvard.edu/abs/2006CBio...16.R711H>). doi:10.1016/j.cub.2006.07.064 (<https://doi.org/10.1016%2Fj.cub.2006.07.064>). PMID 16950098 (<https://pubmed.ncbi.nlm.nih.gov/16950098>). S2CID 2898102 (<https://api.semanticscholar.org/CorpusID:2898102>).
92. Alcamo IE, Pommerville J (2004). *Alcamo's Fundamentals of Microbiology* (<https://archive.org/details/alcamosfundament0000pomm>). Boston, Massachusetts: Jones and Bartlett. p. 590 (<https://archive.org/details/alcamosfundament0000pomm/page/n623>). ISBN 978-0-7637-0067-6.
93. Ulloa, Miguel, Halin, Richard T. (2012). *Illustrated Dictionary of Mycology* (2nd ed.). St. Paul, Minnesota: The American Phytopathological Society. p. 156. ISBN 978-0-89054-400-6.
94. Redecker D, Raab P (2006). "Phylogeny of the glomeromycota (arbuscular mycorrhizal fungi): recent developments and new gene markers" (<http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0885.htm>). *Mycologia*. **98** (6): 885–95. doi:10.3852/mycologia.98.6.885 (<https://doi.org/10.3852%2Fmycologia.98.6.885>). PMID 17486965 (<https://pubmed.ncbi.nlm.nih.gov/17486965>). Archived (<https://web.archive.org/web/20150923230805/http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0885.htm>) from the original on 23 September 2015. Retrieved 5 July 2011.
95. Guarro J, Stchigel AM (July 1999). "Developments in fungal taxonomy" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC100249>). *Clinical Microbiology Reviews*. **12** (3): 454–500. doi:10.1128/CMR.12.3.454 (<https://doi.org/10.1128%2FCMR.12.3.454>). PMC 100249 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC100249>). PMID 10398676 (<https://pubmed.ncbi.nlm.nih.gov/10398676>).
96. Taylor JW, Jacobson DJ, Kroken S, Kasuga T, Geiser DM, Hibbett DS, et al. (October 2000). "Phylogenetic species recognition and species concepts in fungi". *Fungal Genetics and Biology*. **31** (1): 21–32. doi:10.1006/fgb.2000.1228 (<https://doi.org/10.1006%2Ffgbi.2000.1228>). PMID 11118132 (<https://pubmed.ncbi.nlm.nih.gov/11118132>). S2CID 2551424 (<https://api.semanticscholar.org/CorpusID:2551424>).
97. Metzenberg RL, Glass NL (February 1990). "Mating type and mating strategies in Neurospora". *BioEssays*. **12** (2): 53–9. doi:10.1002/bies.950120202 (<https://doi.org/10.1002%2Fbies.950120202>). PMID 2140508 (<https://pubmed.ncbi.nlm.nih.gov/2140508>). S2CID 10818930 (<https://api.semanticscholar.org/CorpusID:10818930>).
98. Jennings & Lysek 1996, pp. 107–114.
99. Deacon 2005, p. 31.
100. Alexopoulos, Mims & Blackwell 1996, pp. 492–493.
101. Jennings & Lysek 1996, p. 142.
102. Deacon 2005, pp. 21–24.
103. "Spore Dispersal in Fungi" (http://www.botany.hawaii.edu/faculty/wong/BOT135/Lect05_b.htm). *botany.hawaii.edu*. Archived (https://web.archive.org/web/20111117180734/http://www.botany.hawaii.edu/faculty/wong/BOT135/Lect05_b.htm) from the original on 17 November 2011. Retrieved 28 December 2018.
104. "Dispersal" (<https://herbarium.usu.edu/fun-with-fungi/dispersal>). *herbarium.usu.edu*. Archived (<https://web.archive.org/web/20181228223648/https://herbarium.usu.edu/fun-with-fungi/dispersal>) from the original on 28 December 2018. Retrieved 28 December 2018.

105. Hassett MO, Fischer MW, Money NP (28 October 2015). "Mushrooms as Rainmakers: How Spores Act as Nuclei for Raindrops" (<https://doi.org/10.1371/journal.pone.0140407>). *PLOS ONE*. **10** (10) e0140407. Bibcode:2015PLoS..1040407H (<https://ui.adsabs.harvard.edu/abs/2015PLoS..1040407H>). doi:10.1371/journal.pone.0140407 (<https://doi.org/10.1371/journal.pone.0140407>). ISSN 1932-6203 (<https://search.worldcat.org/issn/1932-6203>). PMC 4624964 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4624964>). PMID 26509436 (<https://pubmed.ncbi.nlm.nih.gov/26509436>).
106. Kim S, Park H, Gruszewski HA, Schmale DG, Jung S (12 March 2019). "Vortex-induced dispersal of a plant pathogen by raindrop impact" (<https://doi.org/10.1073/pnas.1820318116>). *Proceedings of the National Academy of Sciences*. **116** (11): 4917–4922. Bibcode:2019PNAS..116.4917K (<https://ui.adsabs.harvard.edu/abs/2019PNAS..116.4917K>). doi:10.1073/pnas.1820318116 (<https://doi.org/10.1073/pnas.1820318116>). ISSN 0027-8424 (<https://search.worldcat.org/issn/0027-8424>). PMC 6421443 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6421443>). PMID 30804195 (<https://pubmed.ncbi.nlm.nih.gov/30804195>).
107. Linder MB, Szilvay GR, Nakari-Setälä T, Penttilä ME (November 2005). "Hydrophobins: the protein-amphiphiles of filamentous fungi" (<https://doi.org/10.1016/j.femsre.2005.01.004>). *FEMS Microbiology Reviews*. **29** (5): 877–96. doi:10.1016/j.femsre.2005.01.004 (<https://doi.org/10.1016/j.femsre.2005.01.004>). PMID 16219510 (<https://pubmed.ncbi.nlm.nih.gov/16219510>).
108. Trail F (November 2007). "Fungal cannons: explosive spore discharge in the Ascomycota" (<https://doi.org/10.1111/j.1574-6968.2007.00900.x>). *FEMS Microbiology Letters*. **276** (1): 12–8. doi:10.1111/j.1574-6968.2007.00900.x (<https://doi.org/10.1111/j.1574-6968.2007.00900.x>). PMID 17784861 (<https://pubmed.ncbi.nlm.nih.gov/17784861>).
109. Pringle A, Patek SN, Fischer M, Stolze J, Money NP (2005). "The captured launch of a ballistospore" (<http://www.cybertruffle.org.uk/cyberliber/59350/0097/004/0866.htm>). *Mycologia*. **97** (4): 866–71. doi:10.3852/mycologia.97.4.866 (<https://doi.org/10.3852/mycologia.97.4.866>). PMID 16457355 (<https://pubmed.ncbi.nlm.nih.gov/16457355>). Archived (<https://web.archive.org/web/20160412145956/http://www.cybertruffle.org.uk/cyberliber/59350/0097/004/0866.htm>) from the original on 12 April 2016. Retrieved 5 July 2011.
110. Kirk et al. 2008, p. 495.
111. "Stipitate hydnoid fungi, Hampshire Biodiversity Partnership" (<http://www.hampshirebiodiversity.org.uk/pdf/PublishedPlans/ToothFungiSAPfinal.pdf>) (PDF). Archived (<https://web.archive.org/web/20160304034104/http://www.hampshirebiodiversity.org.uk/pdf/PublishedPlans/ToothFungiSAPfinal.pdf>) (PDF) from the original on 4 March 2016. Retrieved 13 November 2019.
112. Brodie HJ (1975). *The Bird's Nest Fungi*. Toronto, Ontario: University of Toronto Press. p. 80. ISBN 978-0-8020-5307-7.
113. Alexopoulos, Mims & Blackwell 1996, p. 545.
114. Dyer PS, O'Gorman CM (January 2012). "Sexual development and cryptic sexuality in fungi: insights from *Aspergillus* species" (<https://doi.org/10.1111/j.1574-6976.2011.00308.x>). *FEMS Microbiology Reviews*. **36** (1): 165–192. doi:10.1111/j.1574-6976.2011.00308.x (<https://doi.org/10.1111/j.1574-6976.2011.00308.x>). PMID 22091779 (<https://pubmed.ncbi.nlm.nih.gov/22091779>).
115. Yun SH, Berbee ML, Yoder OC, Turgeon BG (1999). "Evolution of the fungal self-fertile reproductive life style from self-sterile ancestors" (<https://doi.org/10.1073/pnas.96.10.5592>). *Proceedings of the National Academy of Sciences of the United States of America*. **96** (10): 5592–7. Bibcode:1999PNAS...96.5592Y (<https://ui.adsabs.harvard.edu/abs/1999PNAS...96.5592Y>). doi:10.1073/pnas.96.10.5592 (<https://doi.org/10.1073/pnas.96.10.5592>). PMC 21905 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC21905>). PMID 10318929 (<https://pubmed.ncbi.nlm.nih.gov/10318929>).
116. Richard S, Almeida Jmgcf CO, Luraschi A, Nielsen O, Pagni M, Hauser PM (2018). "Functional and expression analyses of the *Pneumocystis* MAT genes suggest obligate sexuality through primary homothallism within host lungs" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5821091>). *mBio*. **9** (1) e02201-17. doi:10.1128/mBio.02201-17 (<https://doi.org/10.1128/mBio.02201-17>). PMC 5821091 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5821091>). PMID 29463658 (<https://pubmed.ncbi.nlm.nih.gov/29463658>).

117. Heitman J (2015). "Evolution of sexual reproduction: A view from the fungal kingdom supports an evolutionary epoch with sex before sexes" (<https://doi.org/10.1016%2Fj.fbr.2015.08.002>). *Fungal Biology Reviews*. **29** (3–4): 108–117. Bibcode:2015FunBR..29..108H (<https://ui.adsabs.harvard.edu/abs/2015FunBR..29..108H>). doi:10.1016/j.fbr.2015.08.002 (<https://doi.org/10.1016%2Fj.fbr.2015.08.002>). PMC 4730888 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4730888>). PMID 26834823 (<https://pubmed.ncbi.nlm.nih.gov/26834823>).
118. Jennings & Lysek 1996, pp. 114–115.
119. Furlaneto MC, Pizzirani-Kleiner AA (January 1992). "Intraspecific hybridisation of *Trichoderma pseudokoningii* by anastomosis and by protoplast fusion" (<https://doi.org/10.1111%2Fj.1574-6968.1992.tb05150.x>). *FEMS Microbiology Letters*. **69** (2): 191–5. doi:10.1111/j.1574-6968.1992.tb05150.x (<https://doi.org/10.1111%2Fj.1574-6968.1992.tb05150.x>). PMID 1537549 (<https://pubmed.ncbi.nlm.nih.gov/1537549>).
120. Schardl CL, Craven KD (November 2003). "Interspecific hybridization in plant-associated fungi and oomycetes: a review" (<https://doi.org/10.1046%2Fj.1365-294X.2003.01965.x>). *Molecular Ecology*. **12** (11): 2861–73. Bibcode:2003MolEc..12.2861S (<https://ui.adsabs.harvard.edu/abs/2003MolEc..12.2861S>). doi:10.1046/j.1365-294X.2003.01965.x (<https://doi.org/10.1046%2Fj.1365-294X.2003.01965.x>). PMID 14629368 (<https://pubmed.ncbi.nlm.nih.gov/14629368>). S2CID 25879264 (<https://api.semanticscholar.org/CorpusID:25879264>).
121. Donoghue MJ, Cracraft J (2004). *Assembling the Tree of Life*. Oxford (Oxfordshire), UK: Oxford University Press. p. 187. ISBN 978-0-19-517234-8.
122. Taylor & Taylor 1993, p. 19.
123. Taylor & Taylor 1993, pp. 7–12.
124. Bengtson S, Rasmussen B, Ivarsson M, Muhling J, Broman C, Marone F, et al. (24 April 2017). "Fungus-like mycelial fossils in 2.4-billion-year-old vesicular basalt" (<https://escholarship.org/ucl/item/4883d4qh>). *Nature Ecology & Evolution*. **1** (6): 0141. Bibcode:2017NatEE...1..141B (<https://ui.adsabs.harvard.edu/abs/2017NatEE...1..141B>). doi:10.1038/s41559-017-0141 (<https://doi.org/10.1038%2Fs41559-017-0141>). hdl:20.500.11937/67718 (<https://hdl.handle.net/20.500.11937%2F67718>). PMID 28812648 (<https://pubmed.ncbi.nlm.nih.gov/28812648>). S2CID 25586788 (<https://api.semanticscholar.org/CorpusID:25586788>). Archived (<https://web.archive.org/web/20190715234418/https://escholarship.org/uc/item/4883d4qh>) from the original on 15 July 2019. Retrieved 15 July 2019.
125. Lücking R, Huhndorf S, Pfister DH, Plata ER, Lumbsch HT (2009). "Fungi evolved right on track" (<https://nrs.harvard.edu/urn-3:HUL.InstRepos:14168857>). *Mycologia*. **101** (6): 810–22. doi:10.3852/09-016 (<https://doi.org/10.3852%2F09-016>). PMID 19927746 (<https://pubmed.ncbi.nlm.nih.gov/19927746>). S2CID 6689439 (<https://api.semanticscholar.org/CorpusID:6689439>). Archived (<https://web.archive.org/web/20230726131039/https://dash.harvard.edu/handle/1/14168857>) from the original on 26 July 2023. Retrieved 11 November 2018.
126. "First mushrooms appeared earlier than previously thought" (<https://phys.org/news/2020-01-mushrooms-earlier-previous.html>). Archived (<https://web.archive.org/web/20231027061656/https://phys.org/news/2020-01-mushrooms-earlier-previous.html>) from the original on 27 October 2023. Retrieved 14 October 2023.
127. James TY, Kauff F, Schoch CL, Matheny PB, Hofstetter V, Cox CJ, et al. (October 2006). "Reconstructing the early evolution of Fungi using a six-gene phylogeny". *Nature*. **443** (7113): 818–22. Bibcode:2006Natur.443..818J (<https://ui.adsabs.harvard.edu/abs/2006Natur.443..818J>). doi:10.1038/nature05110 (<https://doi.org/10.1038%2Fnature05110>). PMID 17051209 (<https://pubmed.ncbi.nlm.nih.gov/17051209>). S2CID 4302864 (<https://api.semanticscholar.org/CorpusID:4302864>).
128. Taylor & Taylor 1993, pp. 84–94 & 106–107.
129. Schoch CL, Sung GH, López-Giráldez F, Townsend JP, Miadlikowska J, Hofstetter V, et al. (April 2009). "The Ascomycota tree of life: a phylum-wide phylogeny clarifies the origin and evolution of fundamental reproductive and ecological traits" (<https://doi.org/10.1093%2Fsysbio%2Fsys020>). *Systematic Biology*. **58** (2): 224–39. doi:10.1093/sysbio/syp020 (<https://doi.org/10.1093%2Fsysbio%2Fsys020>). PMID 20525580 (<https://pubmed.ncbi.nlm.nih.gov/20525580>).

130. Zimmer C (22 May 2019). "How Did Life Arrive on Land? A Billion-Year-Old Fungus May Hold Clues – A cache of microscopic fossils from the Arctic hints that fungi reached land long before plants" (<https://www.nytimes.com/2019/05/22/science/fungi-fossils-plants.html>). *The New York Times*. Archived (<https://web.archive.org/web/20190523011853/https://www.nytimes.com/2019/05/22/science/fungi-fossils-plants.html>) from the original on 23 May 2019. Retrieved 23 May 2019.
131. Loron CC, François C, Rainbird RH, Turner EC, Borensztajn S, Javaux EJ (22 May 2019). "Early fungi from the Proterozoic era in Arctic Canada" (<https://insu.hal.science/insu-03586648>). *Nature*. **570** (7760). Springer Science and Business Media LLC: 232–235. Bibcode:2019Natur.570..232L (<https://ui.adsabs.harvard.edu/abs/2019Natur.570..232L>). doi:10.1038/s41586-019-1217-0 (<https://doi.org/10.1038%2Fs41586-019-1217-0>). ISSN 0028-0836 (<https://search.worldcat.org/issn/0028-0836>). PMID 31118507 (<https://pubmed.ncbi.nlm.nih.gov/31118507>). S2CID 162180486 (<https://api.semanticscholar.org/CorpusID:162180486>).
132. Timmer J (22 May 2019). "Billion-year-old fossils may be early fungus" (<https://arstechnica.com/science/2019/05/billion-year-old-fossils-may-be-early-fungus/>). *Ars Technica*. Archived (<https://web.archive.org/web/20190523003551/https://arstechnica.com/science/2019/05/billion-year-old-fossils-may-be-early-fungus/>) from the original on 23 May 2019. Retrieved 23 May 2019.
133. Gan T, Luo T, Pang K, Zhou C, Zhou G, Wan B, et al. (28 January 2021). "Cryptic terrestrial fungus-like fossils of the early Ediacaran Period" (<https://doi.org/10.1038%2Fs41467-021-20975-1>). *Nature Communications*. **12** (1): 641. Bibcode:2021NatCo..12..641G (<https://ui.adsabs.harvard.edu/abs/2021NatCo..12..641G>). doi:10.1038/s41467-021-20975-1 (<https://doi.org/10.1038%2Fs41467-021-20975-1>). ISSN 2041-1723 (<https://search.worldcat.org/issn/2041-1723>). PMC 7843733 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7843733>). PMID 33510166 (<https://pubmed.ncbi.nlm.nih.gov/33510166>).
134. Brundrett MC (2002). "Coevolution of roots and mycorrhizas of land plants" (<https://doi.org/10.1046/j.1469-8137.2002.00397.x>). *New Phytologist*. **154** (2): 275–304. Bibcode:2002NewPh.154..275B (<https://ui.adsabs.harvard.edu/abs/2002NewPh.154..275B>). doi:10.1046/j.1469-8137.2002.00397.x (<https://doi.org/10.1046%2Fj.1469-8137.2002.00397.x>). PMID 33873429 (<https://pubmed.ncbi.nlm.nih.gov/33873429>).
135. Redecker D, Kodner R, Graham LE (September 2000). "Glomalean fungi from the Ordovician". *Science*. **289** (5486): 1920–1. Bibcode:2000Sci...289.1920R (<https://ui.adsabs.harvard.edu/abs/2000Sci...289.1920R>). doi:10.1126/science.289.5486.1920 (<https://doi.org/10.1126%2Fscience.289.5486.1920>). PMID 10988069 (<https://pubmed.ncbi.nlm.nih.gov/10988069>). S2CID 43553633 (<https://api.semanticscholar.org/CorpusID:43553633>).
136. Taylor TN, Taylor EL (1996). "The distribution and interactions of some Paleozoic fungi". *Review of Palaeobotany and Palynology*. **95** (1–4): 83–94. doi:10.1016/S0034-6667(96)00029-2 (<https://doi.org/10.1016%2FS0034-6667%2896%2900029-2>).
137. Dotzler N, Walker C, Krings M, Hass H, Kerp H, Taylor TN, et al. (2009). "Acaulosporoid glomeromycotan spores with a germination shield from the 400-million-year-old Rhynie chert" (https://kuscholarworks.ku.edu/bitstream/1808/13680/1/Taylor_et_al_2009.pdf) (PDF). *Mycological Progress*. **8** (1): 9–18. Bibcode:2009MycPr...8....9D (<https://ui.adsabs.harvard.edu/abs/2009MycPr...8....9D>). doi:10.1007/s11557-008-0573-1 (<https://doi.org/10.1007%2Fs11557-008-0573-1>). hdl:1808/13680 (<https://hdl.handle.net/1808%2F13680>). S2CID 1746303 (<https://api.semanticscholar.org/CorpusID:1746303>).
138. Taylor JW, Berbee ML (2006). "Dating divergences in the Fungal Tree of Life: review and new analyses" (<http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0838.htm>). *Mycologia*. **98** (6): 838–49. doi:10.3852/mycologia.98.6.838 (<https://doi.org/10.3852%2Fmycologia.98.6.838>). PMID 17486961 (<https://pubmed.ncbi.nlm.nih.gov/17486961>). Archived (<https://web.archive.org/web/20160412150130/http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0838.htm>) from the original on 12 April 2016. Retrieved 5 July 2011.
139. Blackwell M, Vilgalys R, James TY, Taylor JW (2009). "Fungi. Eumycota: mushrooms, sac fungi, yeast, molds, rusts, smuts, etc" (<http://tolweb.org/Fungi/2377>). Tree of Life Web Project. Archived (<https://web.archive.org/web/20090413045121/http://tolweb.org/Fungi/2377>) from the original on 13 April 2009. Retrieved 25 April 2009.

140. Honegger R, Edwards D, Axe L (2013). "The earliest records of internally stratified cyanobacterial and algal lichens from the Lower Devonian of the Welsh Borderland" (<https://doi.org/10.1111%2Fnph.12009>). *New Phytologist*. **197** (1): 264–275. Bibcode:2013NewPh.197..264H (<https://ui.adsabs.harvard.edu/abs/2013NewPh.197..264H>). doi:10.1111/nph.12009 (<https://doi.org/10.1111%2Fnph.12009>). PMID 23110612 (<https://pubmed.ncbi.nlm.nih.gov/23110612>).
141. Taylor TN, Hass H, Kerp H, Krings M, Hanlin RT (2005). "Perithecial ascomycetes from the 400 million year old Rhynie chert: an example of ancestral polymorphism" (<http://www.cybertruffle.org.uk/cyberliber/59350/0097/001/0269.htm>). *Mycologia*. **97** (1): 269–85. doi:10.3852/mycologia.97.1.269 (<https://doi.org/10.3852%2Fmycologia.97.1.269>). hdl:1808/16786 (<https://hdl.handle.net/1808%2F16786>). PMID 16389979 (<https://pubmed.ncbi.nlm.nih.gov/16389979>). Archived (<https://web.archive.org/web/20160412150211/http://www.cybertruffle.org.uk/cyberliber/59350/0097/001/0269.htm>) from the original on 12 April 2016. Retrieved 5 July 2011.
142. Dennis RL (1970). "A Middle Pennsylvanian basidiomycete mycelium with clamp connections" (<http://www.cybertruffle.org.uk/cyberliber/59350/0062/003/0578.htm>). *Mycologia*. **62** (3): 578–584. doi:10.2307/3757529 (<https://doi.org/10.2307%2F3757529>). JSTOR 3757529 (<https://www.jstor.org/stable/3757529>). Archived (<https://web.archive.org/web/20180929141016/http://www.cybertruffle.org.uk/cyberliber/59350/0062/003/0578.htm>) from the original on 29 September 2018. Retrieved 5 July 2011.
143. Hibbett DS, Grimaldi D, Donoghue MJ (1995). "Cretaceous mushrooms in amber" (<https://doi.org/10.1038%2F377487a0>). *Nature*. **377** (6549): 487. Bibcode:1995Natur.377..487H (<https://ui.adsabs.harvard.edu/abs/1995Natur.377..487H>). doi:10.1038/377487a0 (<https://doi.org/10.1038%2F377487a0>). S2CID 4346359 (<https://api.semanticscholar.org/CorpusID:4346359>).
144. Hibbett DS, Grimaldi D, Donoghue MJ (1997). "Fossil mushrooms from Miocene and Cretaceous ambers and the evolution of homobasidiomycetes" (<https://doi.org/10.2307%2F2446289>). *American Journal of Botany*. **84** (7): 981–991. doi:10.2307/2446289 (<https://doi.org/10.2307%2F2446289>). JSTOR 2446289 (<https://www.jstor.org/stable/2446289>). PMID 21708653 (<https://pubmed.ncbi.nlm.nih.gov/21708653>). S2CID 22011469 (<https://api.semanticscholar.org/CorpusID:22011469>).
145. Eshet Y, Rampino MR, Visscher H (1995). "Fungal event and palynological record of ecological crisis and recovery across the Permian-Triassic boundary". *Geology*. **23** (1): 967–970. Bibcode:1995Geo....23..967E (<https://ui.adsabs.harvard.edu/abs/1995Geo....23..967E>). doi:10.1130/0091-7613(1995)023<0967:FEAPRO>2.3.CO;2 (<https://doi.org/10.1130%2F0091-7613%281995%29023%3C0967%3AFEAPRO%3E2.3.CO%3B2>). S2CID 58937537 (<https://api.semanticscholar.org/CorpusID:58937537>).
146. Foster CB, Stephenson MH, Marshall C, Logan GA, Greenwood PF (2002). "A revision of Reduviasporonites Wilson 1962: description, illustration, comparison and biological affinities". *Palynology*. **26** (1): 35–58. Bibcode:2002Paly...26...35F (<https://ui.adsabs.harvard.edu/abs/2002Paly...26...35F>). doi:10.2113/0260035 (<https://doi.org/10.2113%2F0260035>).
147. López-Gómez J, Taylor EL (2005). "Permian-Triassic transition in Spain: a multidisciplinary approach". *Palaeogeography, Palaeoclimatology, Palaeoecology*. **229** (1–2): 1–2. doi:10.1016/j.palaeo.2005.06.028 (<https://doi.org/10.1016%2Fj.palaeo.2005.06.028>).
148. Looy CV, Twitchett RJ, Dilcher DL, Van Konijnenburg-Van Cittert JH, Visscher H (July 2001). "Life in the end-Permian dead zone" (<https://doi.org/10.1073%2Fpnas.131218098>). *Proceedings of the National Academy of Sciences of the United States of America*. **98** (14): 7879–83. Bibcode:2001PNAS...98.7879L (<https://ui.adsabs.harvard.edu/abs/2001PNAS...98.7879L>). doi:10.1073/pnas.131218098 (<https://doi.org/10.1073%2Fpnas.131218098>). PMC 35436 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC35436>). PMID 11427710 (<https://pubmed.ncbi.nlm.nih.gov/11427710>). "See image 2"

149. Ward PD, Botha J, Buick R, De Kock MO, Erwin DH, Garrison GH, et al. (February 2005). "Abrupt and gradual extinction among Late Permian land vertebrates in the Karoo basin, South Africa". *Science*. **307** (5710): 709–14. Bibcode:2005Sci...307..709W (<https://ui.adsabs.harvard.edu/abs/2005Sci...307..709W>). CiteSeerX 10.1.1.503.2065 (<https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.503.2065>). doi:10.1126/science.1107068 (<https://doi.org/10.1126/science.1107068>). PMID 15661973 (<https://pubmed.ncbi.nlm.nih.gov/15661973>). S2CID 46198018 (<https://api.semanticscholar.org/CorpusID:46198018>).
150. Casadevall A, Heitman J (16 August 2012). "Fungi and the Rise of Mammals" (<https://doi.org/10.1371/journal.ppat.1002808>). *PLOS Pathogens*. **8** (8) e1002808. doi:10.1371/journal.ppat.1002808 (<https://doi.org/10.1371/journal.ppat.1002808>). PMC 3420938 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3420938>). PMID 22916007 (<https://pubmed.ncbi.nlm.nih.gov/22916007>). "That ecological calamity was accompanied by massive deforestation, an event followed by a fungal bloom, as the earth became a massive compost."
151. Shalchian-Tabrizi K, Minge MA, Espelund M, Orr R, Ruden T, Jakobsen KS, et al. (2008). "Multigene phylogeny of choanozoa and the origin of animals" (<https://doi.org/10.1371/journal.pone.0002098>). *PLOS ONE*. **3** (5) e2098. Bibcode:2008PLoS...3.2098S (<https://ui.adsabs.harvard.edu/abs/2008PLoS...3.2098S>). doi:10.1371/journal.pone.0002098 (<https://doi.org/10.1371/journal.pone.0002098>). PMC 2346548 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2346548>). PMID 18461162 (<https://pubmed.ncbi.nlm.nih.gov/18461162>).
152. Li Y, Steenwyk JL, Chang Y, Wang Y, James TY, Stajich JE, et al. (2021). "A genome-scale phylogeny of the kingdom Fungi" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8347878>). *Current Biology*. **31** (8): 1653–1665. Bibcode:2021CBio...31E1653L (<https://ui.adsabs.harvard.edu/abs/2021CBio...31E1653L>). doi:10.1016/j.cub.2021.01.074 (<https://doi.org/10.1016/j.cub.2021.01.074>). PMC 8347878 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8347878>). PMID 33607033 (<https://pubmed.ncbi.nlm.nih.gov/33607033>).
153. "Palaeos Fungi: Fungi" (<https://web.archive.org/web/20120620205340/http://palaeos.com/fungi/fungi.html>). Archived from the original (<http://palaeos.com/fungi/fungi.html>) on 20 June 2012. for an introduction to fungal taxonomy, including controversies. archive (<https://web.archive.org/web/20041114121617/http://www.palaeos.com/Fungi/default.htm>)
154. Celio GJ, Padamsee M, Dentinger BT, Bauer R, McLaughlin DJ (2006). "Assembling the Fungal Tree of Life: constructing the structural and biochemical database". *Mycologia*. **98** (6): 850–9. doi:10.3852/mycologia.98.6.850 (<https://doi.org/10.3852/mycologia.98.6.850>). PMID 17486962 (<https://pubmed.ncbi.nlm.nih.gov/17486962>). S2CID 23123595 (<https://api.semanticscholar.org/CorpusID:23123595>).
155. Rossman AY (2014). "Lessons learned from moving to one scientific name for fungi" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4107901>). *IMA Fungus*. **5** (1): 81–89. doi:10.5598/imafungus.2014.05.01.10 (<https://doi.org/10.5598/imafungus.2014.05.01.10>). PMC 4107901 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4107901>). PMID 25083410 (<https://pubmed.ncbi.nlm.nih.gov/25083410>).
156. Redhead S, Norvell L (2013). "MycoBank, Index Fungorum, and Fungal Names recommended as official nomenclatural repositories for 2013" (<https://www.researchgate.net/publication/255719633>). *IMA Fungus*. **3** (2): 44–45.
157. Silar P (2016). *Protistes Eucaryotes: Origine, Evolution et Biologie des Microbes Eucaryotes* (<https://hal.archives-ouvertes.fr/hal-01263138/document>). HAL. p. 462. ISBN 978-2-9555841-0-1. Archived (<https://web.archive.org/web/20170925132023/https://hal.archives-ouvertes.fr/hal-01263138/document>) from the original on 25 September 2017. Retrieved 7 April 2016.
158. Esser K (2014). McLaughlin DJ, Spatafora JW (eds.). *Systematics and Evolution* (<https://www.springer.com/gp/book/9783642553172>). Springer. p. 461. doi:10.1007/978-3-642-55318-9 (<https://doi.org/10.1007/978-3-642-55318-9>). ISBN 978-3-642-55317-2. S2CID 46141350 (<https://api.semanticscholar.org/CorpusID:46141350>). Archived (<https://web.archive.org/web/2021041500152/https://www.springer.com/gp/book/9783642553172>) from the original on 15 April 2021. Retrieved 30 September 2020.

159. Tedersoo L, Sanchez-Ramirez S, Koljalg U, Bahram M, Doring M, Schigel D, et al. (22 February 2018). "High-level classification of the Fungi and a tool for evolutionary ecological analyses" (<https://doi.org/10.1007%2Fs13225-018-0401-0>). *Fungal Diversity*. **90** (1): 135–159. doi:10.1007/s13225-018-0401-0 (<https://doi.org/10.1007%2Fs13225-018-0401-0>).
160. Naranjo-Ortiz MA, Gabaldón T (2019). "Fungal evolution: Diversity, taxonomy and phylogeny of the Fungi" (<https://doi.org/10.1111%2Fbrv.12550>). *Biological Reviews*. **94** (6): 2101–2137. doi:10.1111/brv.12550 (<https://doi.org/10.1111%2Fbrv.12550>). PMC 6899921 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6899921>). PMID 31659870 (<https://pubmed.ncbi.nlm.nih.gov/31659870>).
161. Han B, Weiss LM, Heitman J, Stukenbrock EH (2017). "Microsporidia: Obligate intracellular pathogens within the fungal kingdom" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5613672>). *Microbiology Spectrum*. **5** (2) 5.2.03. doi:10.1128/microbiolspec.FUNK-0018-2016 (<https://doi.org/10.1128%2Fmicrobiolspec.FUNK-0018-2016>). PMC 5613672 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5613672>). PMID 28944750 (<https://pubmed.ncbi.nlm.nih.gov/28944750>).
162. James TY, Letcher PM, Longcore JE, Mozley-Standridge SE, Porter D, Powell MJ, et al. (2006). "A molecular phylogeny of the flagellated fungi (Chytridiomycota) and description of a new phylum (Blastocladiomycota)" (<http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0860.htm>). *Mycologia*. **98** (6): 860–71. doi:10.3852/mycologia.98.6.860 (<https://doi.org/10.3852%2Fmycologia.98.6.860>). PMID 17486963 (<https://pubmed.ncbi.nlm.nih.gov/17486963>). Archived (<https://web.archive.org/web/20150923230802/http://www.cybertruffle.org.uk/cyberliber/59350/0098/006/0860.htm>) from the original on 23 September 2015. Retrieved 5 July 2011.
163. Lockhart RJ, Van Dyke MI, Beadle IR, Humphreys P, McCarthy AJ (August 2006). "Molecular biological detection of anaerobic gut fungi (Neocallimastigales) from landfill sites" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1538735>). *Applied and Environmental Microbiology*. **72** (8): 5659–61. Bibcode:2006ApEnM..72.5659L (<https://ui.adsabs.harvard.edu/abs/2006ApEnM..72.5659L>). doi:10.1128/AEM.01057-06 (<https://doi.org/10.1128%2FAEM.01057-06>). PMC 1538735 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1538735>). PMID 16885325 (<https://pubmed.ncbi.nlm.nih.gov/16885325>).
164. Remy W, Taylor TN, Hass H, Kerp H (December 1994). "Four hundred-million-year-old vesicular arbuscular mycorrhizae" (<https://doi.org/10.1073%2Fpnas.91.25.11841>). *Proceedings of the National Academy of Sciences of the United States of America*. **91** (25): 11841–3. Bibcode:1994PNAS...9111841R (<https://ui.adsabs.harvard.edu/abs/1994PNAS...9111841R>). doi:10.1073/pnas.91.25.11841 (<https://doi.org/10.1073%2Fpnas.91.25.11841>). PMC 45331 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC45331>). PMID 11607500 (<https://pubmed.ncbi.nlm.nih.gov/11607500>).
165. Schüssler A, Schwarzott D, Walker C (2001). "A new fungal phylum, the Glomeromycota: phylogeny and evolution". *Mycological Research*. **105** (12): 1413–1421. doi:10.1017/S0953756201005196 (<https://doi.org/10.1017%2FS0953756201005196>). S2CID 82128210 (<https://api.semanticscholar.org/CorpusID:82128210>).
166. Alexopoulos, Mims & Blackwell 1996, p. 145.
167. Walther G, Wagner L, Kurzai O (2019). "Updates on the taxonomy of Mucorales with an emphasis on clinically important taxa" (<https://doi.org/10.3390%2Fjof5040106>). *Journal of Fungi*. **5** (4): 106. doi:10.3390/jof5040106 (<https://doi.org/10.3390%2Fjof5040106>). PMC 6958464 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6958464>). PMID 31739583 (<https://pubmed.ncbi.nlm.nih.gov/31739583>).
168. For an example, see Samuels GJ (February 2006). "Trichoderma: systematics, the sexual state, and ecology" (<https://zenodo.org/record/1235933>). *Phytopathology*. **96** (2): 195–206. Bibcode:2006PhPat..96..195S (<https://ui.adsabs.harvard.edu/abs/2006PhPat..96..195S>). doi:10.1094/PHYTO-96-0195 (<https://doi.org/10.1094%2FPHYTO-96-0195>). PMID 18943925 (<https://pubmed.ncbi.nlm.nih.gov/18943925>).
169. Aramayo R, Selker EU (2013). "Neurospora crassa, a model system for epigenetics research" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3783048>). *Cold Spring Harbor Perspectives in Biology*. **5** (10) a017921. doi:10.1101/cshperspect.a017921 (<https://doi.org/10.1101%2Fcshperspect.a017921>). PMC 3783048 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3783048>). PMID 24086046 (<https://pubmed.ncbi.nlm.nih.gov/24086046>).

170. Olicón-Hernández DR, Araiza-Villanueva MG, Pardo JP, Aranda E, Guerra-Sánchez G (2019). "New insights of *Ustilago maydis* as yeast model for genetic and biotechnological research: A review". *Current Microbiology*. **76** (8): 917–926. doi:10.1007/s00284-019-01629-4 (<https://doi.org/10.1007%2Fs00284-019-01629-4>). PMID 30689003 (<https://pubmed.ncbi.nlm.nih.gov/30689003/>). S2CID 59307118 (<https://api.semanticscholar.org/CorpusID:59307118>).
171. Rhimi W, Theelen B, Boekhout T, Otranto D, Cafarchia C (2020). "Malassezia spp. yeasts of emerging concern in fungemia" (<https://doi.org/10.3389%2Ffcimb.2020.00370>). *Frontiers in Cellular and Infection Microbiology*. **10**: 370. doi:10.3389/fcimb.2020.00370 (<https://doi.org/10.3389%2Ffcimb.2020.00370>). PMC 7399178 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7399178/>). PMID 32850475 (<https://pubmed.ncbi.nlm.nih.gov/32850475/>).
172. Perfect JR (June 2006). "Cryptococcus neoformans: the yeast that likes it hot" (<https://doi.org/10.1111%2Fj.1567-1364.2006.00051.x>). *FEMS Yeast Research*. **6** (4): 463–8. doi:10.1111/j.1567-1364.2006.00051.x (<https://doi.org/10.1111%2Fj.1567-1364.2006.00051.x>). PMID 16696642 (<https://pubmed.ncbi.nlm.nih.gov/16696642/>).
173. Leontyev DV, Schnittler M (2017). "The Phylogeny of Myxomycetes". In Stephenson SL, Rojas C (eds.). *Myxomycetes. Biology, Systematics, Biogeography, and Ecology*. Academic Press. pp. 83–106. doi:10.1016/B978-0-12-805089-7.00003-2 (<https://doi.org/10.1016%2FB978-0-12-805089-7.00003-2>). ISBN 978-0-12-805089-7.
174. Blackwell M, Spatafora JW (2004). "Fungi and their allies". In Bills GF, Mueller GM, Foster MS (eds.). *Biodiversity of Fungi: Inventory and Monitoring Methods*. Amsterdam: Elsevier Academic Press. pp. 18–20. ISBN 978-0-12-509551-8.
175. Amoroso MJ, Benimeli CS, Cuozzo SA (2013). *Actinobacteria: application in bioremediation and production of industrial enzymes* (<https://www.crcpress.com/Actinobacteria-Application-in-Bioremediation-and-Production-of-Industrial/Amoroso-Benimeli-Cuozzo/p/book/9781466578739>). CRC Press, Taylor & Francis Group. p. 33. ISBN 978-1-4665-7873-9.
176. "An Introduction to Soil Biology" (<https://www.humankindoregon.com/soil-biology>). *Humankind Oregon*. Archived (<https://web.archive.org/web/20200731225405/https://www.humankindoregon.com/soil-biology>) from the original on 31 July 2020. Retrieved 13 November 2019.
177. Gadd GM (January 2007). "Geomycology: biogeochemical transformations of rocks, minerals, metals and radionuclides by fungi, bioweathering and bioremediation". *Mycological Research*. **111** (Pt 1): 3–49. doi:10.1016/j.mycres.2006.12.001 (<https://doi.org/10.1016%2Fj.mycres.2006.12.001>). PMID 17307120 (<https://pubmed.ncbi.nlm.nih.gov/17307120/>).
178. Lindahl BD, Ihrmark K, Boberg J, Trumbore SE, Höglberg P, Stenlid J, et al. (2007). "Spatial separation of litter decomposition and mycorrhizal nitrogen uptake in a boreal forest" (<https://www.escholarship.org/uc/item/1r43h5sj>). *The New Phytologist*. **173** (3): 611–20. Bibcode:2007NewPh.173..611L (<https://ui.adsabs.harvard.edu/abs/2007NewPh.173..611L>). doi:10.1111/j.1469-8137.2006.01936.x (<https://doi.org/10.1111%2Fj.1469-8137.2006.01936.x>). hdl:11858/00-001M-0000-0027-D56D-D (<https://hdl.handle.net/11858%2F00-001M-0000-0027-D56D-D>). PMID 17244056 (<https://pubmed.ncbi.nlm.nih.gov/17244056/>). Archived (<https://web.archive.org/web/20200612221001/https://escholarship.org/uc/item/1r43h5sj>) from the original on 12 June 2020. Retrieved 24 September 2019.
179. Barea JM, Pozo MJ, Azcón R, Azcón-Aguilar C (July 2005). "Microbial co-operation in the rhizosphere" (<https://doi.org/10.1093%2Fjxb%2Feri197>). *Journal of Experimental Botany*. **56** (417): 1761–78. doi:10.1093/jxb/eri197 (<https://doi.org/10.1093%2Fjxb%2Feri197>). PMID 15911555 (<https://pubmed.ncbi.nlm.nih.gov/15911555/>).
180. Aanen DK (June 2006). "As you reap, so shall you sow: coupling of harvesting and inoculating stabilizes the mutualism between termites and fungi" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1618886>). *Biology Letters*. **2** (2): 209–12. doi:10.1098/rsbl.2005.0424 (<https://doi.org/10.1098%2Frsbl.2005.0424>). PMC 1618886 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1618886>). PMID 17148364 (<https://pubmed.ncbi.nlm.nih.gov/17148364/>).
181. Nikoh N, Fukatsu T (April 2000). "Interkingdom host jumping underground: phylogenetic analysis of entomoparasitic fungi of the genus *Cordyceps*" (<https://doi.org/10.1093%2Fxfordjournals.molbev.a026341>). *Molecular Biology and Evolution*. **17** (4): 629–38. doi:10.1093/oxfordjournals.molbev.a026341 (<https://doi.org/10.1093%2Fxfordjournals.molbev.a026341>). PMID 10742053 (<https://pubmed.ncbi.nlm.nih.gov/10742053/>).

182. Perotto S, Bonfante P (December 1997). "Bacterial associations with mycorrhizal fungi: close and distant friends in the rhizosphere". *Trends in Microbiology*. **5** (12): 496–501. doi:10.1016/S0966-842X(97)01154-2 (<https://doi.org/10.1016%2FS0966-842X%2897%2901154-2>). PMID 9447662 (<https://pubmed.ncbi.nlm.nih.gov/9447662/>).
183. Arnold AE, Mejía LC, Kyllo D, Rojas EI, Maynard Z, Robbins N, et al. (December 2003). "Fungal endophytes limit pathogen damage in a tropical tree" (<https://doi.org/10.1073%2Fpnas.2533483100>). *Proceedings of the National Academy of Sciences of the United States of America*. **100** (26): 15649–54. Bibcode:2003PNAS..10015649A (<https://ui.adsabs.harvard.edu/abs/2003PNAS..10015649A>). doi:10.1073/pnas.2533483100 (<https://doi.org/10.1073%2Fpnas.2533483100>). PMC 307622 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC307622/>). PMID 14671327 (<https://pubmed.ncbi.nlm.nih.gov/14671327/>).
184. Paszkowski U (August 2006). "Mutualism and parasitism: the yin and yang of plant symbioses". *Current Opinion in Plant Biology*. **9** (4): 364–70. Bibcode:2006COPB....9..364P (<https://ui.adsabs.harvard.edu/abs/2006COPB....9..364P>). doi:10.1016/j.pbi.2006.05.008 (<https://doi.org/10.1016%2Fj.pbi.2006.05.008>). PMID 16713732 (<https://pubmed.ncbi.nlm.nih.gov/16713732/>).
185. Hube B (August 2004). "From commensal to pathogen: stage- and tissue-specific gene expression of *Candida albicans*". *Current Opinion in Microbiology*. **7** (4): 336–41. doi:10.1016/j.mib.2004.06.003 (<https://doi.org/10.1016%2Fj.mib.2004.06.003>). PMID 15288621 (<https://pubmed.ncbi.nlm.nih.gov/15288621/>).
186. Bonfante P (April 2003). "Plants, mycorrhizal fungi and endobacteria: a dialog among cells and genomes" (<https://www.biodiversitylibrary.org/part/9240>). *The Biological Bulletin*. **204** (2): 215–20. doi:10.2307/1543562 (<https://doi.org/10.2307%2F1543562>). JSTOR 1543562 (<https://www.jstor.org/stable/1543562>). PMID 12700157 (<https://pubmed.ncbi.nlm.nih.gov/12700157/>). S2CID 12377410 (<https://api.semanticscholar.org/CorpusID:12377410>). Archived (<https://web.archive.org/web/20220421230922/https://www.biodiversitylibrary.org/part/9240>) from the original on 21 April 2022. Retrieved 20 May 2021.
187. van der Heijden MG, Streitwolf-Engel R, Riedl R, Siegrist S, Neudecker A, Ineichen K, et al. (2006). "The mycorrhizal contribution to plant productivity, plant nutrition and soil structure in experimental grassland" (<https://doi.org/10.1111%2Fj.1469-8137.2006.01862.x>). *The New Phytologist*. **172** (4): 739–52. Bibcode:2006NewPh.172..739V (<https://ui.adsabs.harvard.edu/abs/2006NewPh.172..739V>). doi:10.1111/j.1469-8137.2006.01862.x (<https://doi.org/10.1111%2Fj.1469-8137.2006.01862.x>). PMID 17096799 (<https://pubmed.ncbi.nlm.nih.gov/17096799/>). S2CID 17048094 (<https://api.semanticscholar.org/CorpusID:17048094>).
188. Heijden MG (15 April 2016). "Underground networking". *Science*. **352** (6283): 290–291. Bibcode:2016Sci...352..290H (<https://ui.adsabs.harvard.edu/abs/2016Sci...352..290H>). doi:10.1126/science.aaf4694 (<https://doi.org/10.1126%2Fscience.aaf4694>). hdl:1874/344517 (<https://hdl.handle.net/1874%2F344517>). ISSN 0036-8075 (<https://search.worldcat.org/issn/0036-8075>). PMID 27081054 (<https://pubmed.ncbi.nlm.nih.gov/27081054/>). S2CID 133399719 (<https://api.semanticscholar.org/CorpusID:133399719>).
189. Selosse MA, Richard F, He X, Simard SW (November 2006). "Mycorrhizal networks: des liaisons dangereuses?". *Trends in Ecology & Evolution*. **21** (11): 621–8. Bibcode:2006TEcoE..21..621S (<https://ui.adsabs.harvard.edu/abs/2006TEcoE..21..621S>). doi:10.1016/j.tree.2006.07.003 (<https://doi.org/10.1016%2Fj.tree.2006.07.003>). PMID 16843567 (<https://pubmed.ncbi.nlm.nih.gov/16843567/>).
190. Yong E (14 April 2016). "Trees Have Their Own Internet" (<https://www.theatlantic.com/science/archive/2016/04/the-wood-wide-web/478224/>). *The Atlantic*. Archived (<https://web.archive.org/web/20190328164827/https://www.theatlantic.com/science/archive/2016/04/the-wood-wide-web/478224/>) from the original on 28 March 2019. Retrieved 9 March 2019.
191. Merckx V, Bidartondo MI, Hynson NA (December 2009). "Myco-heterotrophy: when fungi host plants" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2778383>). *Annals of Botany*. **104** (7): 1255–61. doi:10.1093/aob/mcp235 (<https://doi.org/10.1093%2Faob%2Fmcp235>). PMC 2778383 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2778383>). PMID 19767309 (<https://pubmed.ncbi.nlm.nih.gov/19767309/>).

192. Schulz B, Boyle C (June 2005). "The endophytic continuum". *Mycological Research*. **109** (Pt 6): 661–86. doi:10.1017/S095375620500273X (<https://doi.org/10.1017%2FS095375620500273X>). PMID 16080390 (<https://pubmed.ncbi.nlm.nih.gov/16080390/>). S2CID 23182632 (<https://api.semanticscholar.org/CorpusID:23182632>).
193. Clay K, Schardl C (October 2002). "Evolutionary origins and ecological consequences of endophyte symbiosis with grasses". *The American Naturalist*. 160 Suppl 4 (suppl. 4): S99 – S127. Bibcode:2002ANat..160S..99C (<https://ui.adsabs.harvard.edu/abs/2002ANat..160S..99C>). doi:10.1086/342161 (<https://doi.org/10.1086%2F342161>). PMID 18707456 (<https://pubmed.ncbi.nlm.nih.gov/18707456/>). S2CID 23909652 (<https://api.semanticscholar.org/CorpusID:23909652>).
194. Brodo IM, Sharnoff SD (2001). *Lichens of North America*. New Haven, Connecticut: Yale University Press. ISBN 978-0-300-08249-4.
195. Raven PH, Evert RF, Eichhorn, SE (2005). "14—Fungi" (https://archive.org/details/biologyofplants00rave_0). *Biology of Plants* (7 ed.). W. H. Freeman. p. 290 (https://archive.org/details/biologyofplants00rave_0/page/290). ISBN 978-0-7167-1007-3.
196. Deacon 2005, p. 267.
197. Purvis W (2000). *Lichens* (<https://archive.org/details/lichens00purv/page/49>). Washington, D.C.: Smithsonian Institution Press in association with the Natural History Museum, London. pp. 49–75 (<https://archive.org/details/lichens00purv/page/49>). ISBN 978-1-56098-879-3.
198. Kirk et al. 2008, p. 378.
199. Garrido-Benavent I, Pérez-Ortega S (2017). "Past, present, and future research in bipolar lichen-forming fungi and their photobionts" (<https://doi.org/10.3732%2Fajb.1700182>). *American Journal of Botany*. **104** (11): 1660–1674. doi:10.3732/ajb.1700182 (<https://doi.org/10.3732%2Fajb.1700182>).
200. Deacon 2005, pp. 267–276.
201. Chomicki G, Renner SS (2017). "The interactions of ants with their biotic environment" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5360932>). *Proceedings of the Royal Society B: Biological Sciences*. **284** (1850) 20170013. doi:10.1098/rspb.2017.0013 (<https://doi.org/10.1098/rspb.2017.0013>). PMC 5360932 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5360932>). PMID 28298352 (<https://pubmed.ncbi.nlm.nih.gov/28298352>).
202. Joseph R, Keyhani NO (2021). "Fungal mutualisms and pathosystems: life and death in the ambrosia beetle mycangia". *Applied Microbiology and Biotechnology*. **105** (9): 3393–3410. doi:10.1007/s00253-021-11268-0 (<https://doi.org/10.1007%2Fs00253-021-11268-0>). PMID 33837831 (<https://pubmed.ncbi.nlm.nih.gov/33837831>). S2CID 233200379 (<https://api.semanticscholar.org/CorpusID:233200379>).
203. Deacon 2005, p. 277.
204. "Entomologists: Brazilian Stingless Bee Must Cultivate Special Type of Fungus to Survive" (<http://www.sci-news.com/biology/science-brazilian-stingless-bee-monascus-fungus-03372.html>). Sci-News.com. 23 October 2015. Archived (<https://web.archive.org/web/20151025012743/http://www.sci-news.com/biology/science-brazilian-stingless-bee-monascus-fungus-03372.html>) from the original on 25 October 2015. Retrieved 25 October 2015.
205. Nguyen NH, Suh SO, Blackwell M (2007). "Five novel *Candida* species in insect-associated yeast clades isolated from Neuroptera and other insects" (<http://www.cybertruffle.org.uk/cyberliber/59350/0099/006/0842.htm>). *Mycologia*. **99** (6): 842–58. doi:10.3852/mycologia.99.6.842 (<https://doi.org/10.3852%2Fmycologia.99.6.842>). PMID 18333508 (<https://pubmed.ncbi.nlm.nih.gov/18333508>). Archived (<https://web.archive.org/web/20170507072249/http://www.cybertruffle.org.uk/cyberliber/59350/0099/006/0842.htm>) from the original on 7 May 2017. Retrieved 5 July 2011.
206. Filipiak M, Weiner J (March 2017). "Nutritional dynamics during the development of xylophagous beetles related to changes in the stoichiometry of 11 elements" (<https://doi.org/10.1111%2Fphen.12168>). *Physiological Entomology*. **42** (1): 73–84. doi:10.1111/phen.12168 (<https://doi.org/10.1111%2Fphen.12168>).

207. Ulyshen MD (2018). "Nutrient Dynamics in Decomposing Dead Wood in the Context of Wood Eater Requirements: The Ecological Stoichiometry of Saproxylophagous Insects". *Saproxylic Insects* (<https://depot.ceon.pl/handle/123456789/15394?show=full>). Zoological Monographs. Vol. 1. Springer, Cham. pp. 429–469. doi:10.1007/978-3-319-75937-1_13 (https://doi.org/10.1007%2F978-3-319-75937-1_13). ISBN 978-3-319-75937-1.
208. Ulyshen MD (2018). "Insect-Fungus Interactions in Dead Wood Systems". *Saproxylic Insects*. Zoological Monographs. Vol. 1. Springer, Cham. pp. 377–427. doi:10.1007/978-3-319-75937-1_12 (https://doi.org/10.1007%2F978-3-319-75937-1_12). ISBN 978-3-319-75936-4.
209. Filipiak M, Sobczyk Ł, Weiner J (2016). "Fungal transformation of tree stumps into a suitable resource for xylophagous beetles via changes in elemental ratios" (<https://doi.org/10.3390%2Finsects7020013>). *Insects*. 7 (2): 13. doi:10.3390/insects7020013 (<https://doi.org/10.3390%2Finsects7020013>). PMC 4931425 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4931425>).
210. Jakovlev J (2012). "Fungal hosts of mycetophilids (Diptera: Sciaroidea excluding Sciaridae): a review" (<https://www.researchgate.net/publication/254268258>). *Mycology*. 3 (1): 11–23. doi:10.1080/21501203.2012.662533 (<https://doi.org/10.1080%2F21501203.2012.662533>). S2CID 82107953 (<https://api.semanticscholar.org/CorpusID:82107953>).
211. Fernandez J, Orth K (2018). "Rise of a cereal killer: the biology of *Magnaporthe oryzae* biotrophic growth" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6003838>). *Trends in Microbiology*. 26 (7): 582–597. doi:10.1016/j.tim.2017.12.007 (<https://doi.org/10.1016%2Fj.tim.2017.12.007>). PMC 6003838 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6003838>). PMID 29395728 (<https://pubmed.ncbi.nlm.nih.gov/29395728>).
212. Santini A, Battisti A (2019). "Complex insect-pathogen interactions in tree pandemics" (<https://doi.org/10.3389%2Ffphys.2019.00550>). *Frontiers in Physiology*. 10: 550. doi:10.3389/fphys.2019.00550 (<https://doi.org/10.3389%2Ffphys.2019.00550>). PMC 6517489 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6517489>). PMID 31133880 (<https://pubmed.ncbi.nlm.nih.gov/31133880>).
213. Rigling D, Prospero S (2018). "*Cryphonectria parasitica*, the causal agent of chestnut blight: invasion history, population biology and disease control" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6638123>). *Molecular Plant Pathology*. 19 (1): 7–20. Bibcode:2018MolPP..19....7R (<https://ui.adsabs.harvard.edu/abs/2018MolPP..19....7R>). doi:10.1111/mpp.12542 (<https://doi.org/10.1111%2Fmpp.12542>). PMC 6638123 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6638123>). PMID 28142223 (<https://pubmed.ncbi.nlm.nih.gov/28142223>).
214. Yang Y, Yang E, An Z, Liu X (May 2007). "Evolution of nematode-trapping cells of predatory fungi of the Orbiliaceae based on evidence from rRNA-encoding DNA and multiprotein sequences" (<https://doi.org/10.1073%2Fpnas.0702770104>). *Proceedings of the National Academy of Sciences of the United States of America*. 104 (20): 8379–84. Bibcode:2007PNAS..104.8379Y (<https://ui.adsabs.harvard.edu/abs/2007PNAS..104.8379Y>). doi:10.1073/pnas.0702770104 (<https://doi.org/10.1073%2Fpnas.0702770104>). PMC 1895958 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1895958>). PMID 17494736 (<https://pubmed.ncbi.nlm.nih.gov/17494736>).
215. Koeck M, Hardham A, Dodds, P.N. (2011). "The role of effectors of biotrophic and hemibiotrophic fungi in infection" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3218205>). *Cellular Microbiology*. 13 (12): 1849–1857. doi:10.1111/j.1462-5822.2011.01665.x (<https://doi.org/10.1111%2Fj.1462-5822.2011.01665.x>). PMC 3218205 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3218205>). PMID 21848815 (<https://pubmed.ncbi.nlm.nih.gov/21848815>).
216. "Asterotremella gen. nov. albida, an anamorphic tremelloid yeast isolated from the agarics *Asterophora lycoperdoides* and *Asterophora parasitica*" (<https://www.researchgate.net/publication/6114636>). Retrieved 19 April 2019 – via ResearchGate.
217. Nielsen K, Heitman J (2007). "Sex and Virulence of Human Pathogenic Fungi". *Fungal Genomics*. Advances in Genetics. Vol. 57. Elsevier. pp. 143–73. doi:10.1016/S0065-2660(06)57004-X (<https://doi.org/10.1016%2FS0065-2660%2806%2957004-X>). ISBN 978-0-12-017657-1. PMID 17352904 (<https://pubmed.ncbi.nlm.nih.gov/17352904>).

218. Brakhage AA (December 2005). "Systemic fungal infections caused by Aspergillus species: epidemiology, infection process and virulence determinants". *Current Drug Targets*. **6** (8): 875–86. doi:10.2174/138945005774912717 (<https://doi.org/10.2174%2F138945005774912717>). PMID 16375671 (<https://pubmed.ncbi.nlm.nih.gov/16375671>).
219. Kauffman CA (January 2007). "Histoplasmosis: a clinical and laboratory update" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1797635>). *Clinical Microbiology Reviews*. **20** (1): 115–32. doi:10.1128/CMR.00027-06 (<https://doi.org/10.1128%2FCMR.00027-06>). PMC 1797635 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1797635>). PMID 17223625 (<https://pubmed.ncbi.nlm.nih.gov/17223625>).
220. Cushion MT, Smulian AG, Slaven BE, Sesterhenn T, Arnold J, Staben C, et al. (2007). "Transcriptome of *Pneumocystis carinii* during fulminate infection: carbohydrate metabolism and the concept of a compatible parasite" (<https://doi.org/10.1371/journal.pone.0000423>). *PLOS ONE*. **2** (5) e423. Bibcode:2007PLoS...2..423C (<https://ui.adsabs.harvard.edu/abs/2007PLoS...2..423C>). doi:10.1371/journal.pone.0000423 (<https://doi.org/10.1371/journal.pone.0000423>). PMC 1855432 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1855432>). PMID 17487271 (<https://pubmed.ncbi.nlm.nih.gov/17487271>).
221. Cook GC, Zumla AI (2008). *Manson's Tropical Diseases: Expert Consult*. Edinburgh, Scotland: Saunders Ltd. p. 347. ISBN 978-1-4160-4470-3.
222. Simon-Nobbe B, Denk U, Pöll V, Rid R, Breitenbach M (2008). "The spectrum of fungal allergy" (<https://doi.org/10.1159/000107578>). *International Archives of Allergy and Immunology*. **145** (1): 58–86. doi:10.1159/000107578 (<https://doi.org/10.1159/000107578>). PMID 17709917 (<https://pubmed.ncbi.nlm.nih.gov/17709917>).
223. Thambugala KM, Daranagama DA, Phillips AJ, Kannangara SD, Promputtha I (2020). "Fungi vs. fungi in biocontrol: An overview of fungal antagonists applied against fungal plant pathogens" (<https://doi.org/10.3389/fcimb.2020.604923>). *Frontiers in Cellular and Infection Microbiology*. **10** 604923. doi:10.3389/fcimb.2020.604923 (<https://doi.org/10.3389/fcimb.2020.604923>). PMC 7734056 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7734056>). PMID 33330142 (<https://pubmed.ncbi.nlm.nih.gov/33330142>).
224. Pearson MN, Beever RE, Boine B, Arthur K (January 2009). "Mycoviruses of filamentous fungi and their relevance to plant pathology" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6640375>). *Molecular Plant Pathology*. **10** (1): 115–28. Bibcode:2009MolPP..10..115P (<https://ui.adsabs.harvard.edu/abs/2009MolPP..10..115P>). doi:10.1111/j.1364-3703.2008.00503.x (<https://doi.org/10.1111/j.1364-3703.2008.00503.x>). PMC 6640375 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6640375>). PMID 19161358 (<https://pubmed.ncbi.nlm.nih.gov/19161358>).
225. Bozarth RF (October 1972). "Mycoviruses: a new dimension in microbiology" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474899>). *Environmental Health Perspectives*. **2** (1): 23–39. Bibcode:1972EnvHP...2...23B (<https://ui.adsabs.harvard.edu/abs/1972EnvHP...2...23B>). doi:10.1289/ehp.720223 (<https://doi.org/10.1289%2Fehp.720223>). PMC 1474899 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474899>). PMID 4628853 (<https://pubmed.ncbi.nlm.nih.gov/4628853>).
226. Adamatzky A (2022). "Language of fungi derived from their electrical spiking activity" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8984380>). *Royal Society Open Science*. **9** (4) 211926. arXiv:2112.09907 (<https://arxiv.org/abs/2112.09907>). Bibcode:2022RSOS....911926A (<https://ui.adsabs.harvard.edu/abs/2022RSOS....911926A>). doi:10.1098/rsos.211926 (<https://doi.org/10.1098/rsos.211926>). PMC 8984380 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8984380>). PMID 35425630 (<https://pubmed.ncbi.nlm.nih.gov/35425630>).
227. ELBEIN S (6 June 2023). "Fungi may offer 'jaw-dropping' solution to climate change" (<https://thehill.com/policy/equilibrium-sustainability/4034986-fungi-may-offer-jaw-dropping-solution-to-climate-change/>). The Hill. Archived (<https://web.archive.org/web/20230606030741/https://thehill.com/policy/equilibrium-sustainability/4034986-fungi-may-offer-jaw-dropping-solution-to-climate-change/>) from the original on 6 June 2023. Retrieved 6 June 2023.

228. "Fungi stores a third of carbon from fossil fuel emissions and could be essential to reaching net zero, new study reveals" (<https://www.eurekalert.org/news-releases/991288>). *EurekAlert*. UNIVERSITY OF SHEFFIELD. Archived (<https://web.archive.org/web/2023060610252/https://www.eurekalert.org/news-releases/991288>) from the original on 6 June 2023. Retrieved 6 June 2023.
229. Schardl CL, Panaccione DG, Tudzynski P (2006). "Chapter 2. Ergot Alkaloids – Biology and Molecular Biology". *The Alkaloids: Chemistry and Biology (Volume 63)*. Vol. 63. Elsevier. pp. 45–86. doi:10.1016/S1099-4831(06)63002-2 (<https://doi.org/10.1016%2FS1099-4831%2806%2963002-2>). ISBN 978-0-12-469563-4. PMID 17133714 (<https://pubmed.ncbi.nlm.nih.gov/17133714>).
230. Janik E, Niemcewicz M, Ceremuga M, Stela M, Saluk-Bijak J, Siadkowski A, et al. (2020). "Molecular aspects of mycotoxins—a serious problem for human health" (<https://doi.org/10.3390%2Fijms21218187>). *International Journal of Molecular Sciences*. **21** (21): 8187. doi:10.3390/ijms21218187 (<https://doi.org/10.3390%2Fijms21218187>). PMC 7662353 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7662353>). PMID 33142955 (<https://pubmed.ncbi.nlm.nih.gov/33142955>).
231. Demain AL, Fang A (2000). "The Natural Functions of Secondary Metabolites". *History of Modern Biotechnology I. Advances in Biochemical Engineering/Biotechnology*. Vol. 69. Berlin, Heidelberg: Springer. pp. 1–39. doi:10.1007/3-540-44964-7_1 (https://doi.org/10.1007%2F3-540-44964-7_1). ISBN 978-3-540-67793-2. PMID 11036689 (<https://pubmed.ncbi.nlm.nih.gov/11036689>).
232. Rohlfs M, Albert M, Keller NP, Kempken F (October 2007). "Secondary chemicals protect mould from fungivory" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2391202>). *Biology Letters*. **3** (5): 523–5. doi:10.1098/rsbl.2007.0338 (<https://doi.org/10.1098%2Frsbl.2007.0338>). PMC 2391202 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2391202>). PMID 17686752 (<https://pubmed.ncbi.nlm.nih.gov/17686752>).
233. Molina L, Kahmann R (July 2007). "An *Ustilago maydis* gene involved in H₂O₂ detoxification is required for virulence" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1955693>). *The Plant Cell*. **19** (7): 2293–309. Bibcode:2007PlanC..19.2293M (<https://ui.adsabs.harvard.edu/abs/2007PlanC..19.2293M>). doi:10.1105/tpc.107.052332 (<https://doi.org/10.1105%2Ftpc.107.052332>). PMC 1955693 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1955693>). PMID 17616735 (<https://pubmed.ncbi.nlm.nih.gov/17616735>).
234. Kojic M, Zhou Q, Lisby M, Holloman WK (January 2006). "Rec2 interplay with both Brh2 and Rad51 balances recombinational repair in *Ustilago maydis*" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1346908>). *Molecular and Cellular Biology*. **26** (2): 678–88. doi:10.1128/MCB.26.2.678-688.2006 (<https://doi.org/10.1128%2FMCB.26.2.678-688.2006>). PMC 1346908 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1346908>). PMID 16382157 (<https://pubmed.ncbi.nlm.nih.gov/16382157>).
235. Michod RE, Bernstein H, Nedelcu AM (May 2008). "Adaptive value of sex in microbial pathogens" (<http://www.hummingbirds.arizona.edu/Faculty/Michod/Downloads/IGE%20review%20sex.pdf>) (PDF). *Infection, Genetics and Evolution*. **8** (3): 267–85. Bibcode:2008InfGE...8..267M (<https://ui.adsabs.harvard.edu/abs/2008InfGE...8..267M>). doi:10.1016/j.meegid.2008.01.002 (<https://doi.org/10.1016%2Fj.meegid.2008.01.002>). PMID 18295550 (<https://pubmed.ncbi.nlm.nih.gov/18295550>). Archived (<https://web.archive.org/web/20170516235741/http://www.hummingbirds.arizona.edu/Faculty/Michod/Downloads/IGE%20review%20sex.pdf>) (PDF) from the original on 16 May 2017. Retrieved 22 July 2013.
236. Fan W, Kraus PR, Boily MJ, Heitman J (August 2005). "Cryptococcus neoformans gene expression during murine macrophage infection" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1214536>). *Eukaryotic Cell*. **4** (8): 1420–33. doi:10.1128/EC.4.8.1420-1433.2005 (<https://doi.org/10.1128%2FEC.4.8.1420-1433.2005>). PMC 1214536 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1214536>). PMID 16087747 (<https://pubmed.ncbi.nlm.nih.gov/16087747>).

237. Lin X, Hull CM, Heitman J (April 2005). "Sexual reproduction between partners of the same mating type in *Cryptococcus neoformans*". *Nature*. **434** (7036): 1017–21. Bibcode:2005Natur.434.1017L (<https://ui.adsabs.harvard.edu/abs/2005Natur.434.1017L>). doi:10.1038/nature03448 (<https://doi.org/10.1038%2Fnature03448>). PMID 15846346 (<https://pubmed.ncbi.nlm.nih.gov/15846346/>). S2CID 52857557 (<https://api.semanticscholar.org/CorpusID:52857557>).
238. Fincham JR (March 1989). "Transformation in fungi" (<https://www.ncbi.nlm.nih.gov/pmc/article/s/PMC372721>). *Microbiological Reviews*. **53** (1): 148–70. doi:10.1128/MMBR.53.1.148-170.1989 (<https://doi.org/10.1128%2FMMBR.53.1.148-170.1989>). PMC 372721 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC372721>). PMID 2651864 (<https://pubmed.ncbi.nlm.nih.gov/2651864>).
239. Baghban R, Farajnia S, Rajabibazl M, Ghasemi Y, Mafi A, Hoseinpoor R, et al. (2019). "Yeast expression systems: Overview and recent advances" (<https://doi.org/10.1007%2Fs12033-019-00164-8>). *Molecular Biotechnology*. **61** (5): 365–384. doi:10.1007/s12033-019-00164-8 (<https://doi.org/10.1007%2Fs12033-019-00164-8>). PMID 30805909 (<https://pubmed.ncbi.nlm.nih.gov/30805909>). S2CID 73501127 (<https://api.semanticscholar.org/CorpusID:73501127>).
240. Huang B, Guo J, Yi B, Yu X, Sun L, Chen W (July 2008). "Heterologous production of secondary metabolites as pharmaceuticals in *Saccharomyces cerevisiae*". *Biotechnology Letters*. **30** (7): 1121–37. doi:10.1007/s10529-008-9663-z (<https://doi.org/10.1007%2Fs10529-008-9663-z>). PMID 18512022 (<https://pubmed.ncbi.nlm.nih.gov/18512022>). S2CID 2222358 (<https://api.semanticscholar.org/CorpusID:2222358>).
241. Meyer V, Basenko EY, Benz JP, Braus GH, Caddick MX, Csukai M, et al. (2 April 2020). "Growing a circular economy with fungal biotechnology: a white paper" (<https://doi.org/10.1186%2Fs40694-020-00095-z>). *Fungal Biology and Biotechnology*. **7** (1): 5. doi:10.1186/s40694-020-00095-z (<https://doi.org/10.1186%2Fs40694-020-00095-z>). ISSN 2054-3085 (<https://search.worldcat.org/issn/2054-3085>). PMC 7140391 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7140391>). PMID 32280481 (<https://pubmed.ncbi.nlm.nih.gov/32280481>). S2CID 215411291 (<https://api.semanticscholar.org/CorpusID:215411291>).
242. Jones M, Gandia A, John S, Bismarck A (January 2021). "Leather-like material biofabrication using fungi". *Nature Sustainability*. **4** (1): 9–16. doi:10.1038/s41893-020-00606-1 (<https://doi.org/10.1038%2Fs41893-020-00606-1>). ISSN 2398-9629 (<https://search.worldcat.org/issn/2398-9629>). S2CID 221522085 (<https://api.semanticscholar.org/CorpusID:221522085>).
243. "Plant-based meat substitutes - products with future potential | Bioökonomie.de" (<https://biooeconomie.de/en/topics/in-depth-reports/plant-based-meat-substitutes-products-future-potential>). *biooeconomie.de*. Archived (<https://web.archive.org/web/20231210014627/https://biooeconomie.de/en/topics/in-depth-reports/plant-based-meat-substitutes-products-future-potential>) from the original on 10 December 2023. Retrieved 25 May 2022.
244. Berlin KC, biotechnology ic, Artists HC, Artists H (28 January 2022). "Mushroom meat substitutes: A brief patent overview" (<https://blogs.biomedcentral.com/on-biology/2022/01/28/mushroom-meat-substitutes-a-brief-patent-overview/>). *On Biology*. Archived (<https://web.archive.org/web/20231129012028/https://blogs.biomedcentral.com/on-biology/2022/01/28/mushroom-meat-substitutes-a-brief-patent-overview/>) from the original on 29 November 2023. Retrieved 25 May 2022.
245. Lange L (December 2014). "The importance of fungi and mycology for addressing major global challenges*" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4329327>). *IMA Fungus*. **5** (2): 463–471. doi:10.5598/imafungus.2014.05.02.10 (<https://doi.org/10.5598%2Fimafungus.2014.05.02.10>). ISSN 2210-6340 (<https://search.worldcat.org/issn/2210-6340>). PMC 4329327 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4329327>). PMID 25734035 (<https://pubmed.ncbi.nlm.nih.gov/25734035>).
246. Pathak A, Nowell RW, Wilson CG, Ryan MJ, Barraclough TG (September 2020). "Comparative genomics of Alexander Fleming's original *Penicillium* isolate (IMI 15378) reveals sequence divergence of penicillin synthesis genes" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7515868>). *Scientific Reports*. **10** (1) 15705. Bibcode:2020NatSR..1015705P (<https://ui.adsabs.harvard.edu/abs/2020NatSR..1015705P>). doi:10.1038/s41598-020-72584-5 (<https://doi.org/10.1038%2Fs41598-020-72584-5>). PMC 7515868 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7515868>). PMID 32973216 (<https://pubmed.ncbi.nlm.nih.gov/32973216>).

247. Brakhage AA, Spröte P, Al-Abdallah Q, Gehrke A, Plattner H, Tüncher A (2004). "Regulation of Penicillin Biosynthesis in Filamentous Fungi". *Molecular Biotechnology of Fungal beta-Lactam Antibiotics and Related Peptide Synthetases*. Advances in Biochemical Engineering/Biotechnology. Vol. 88. Berlin, Heidelberg: Springer. pp. 45–90. doi:10.1007/b99257 (<https://doi.org/10.1007%2Fb99257>). ISBN 978-3-540-22032-9. PMID 15719552 (<https://pubmed.ncbi.nlm.nih.gov/15719552>).
248. Pan A, Lorenzotti S, Zoncada A (January 2008). "Registered and investigational drugs for the treatment of methicillin-resistant *Staphylococcus aureus* infection". *Recent Patents on Anti-Infective Drug Discovery*. **3** (1): 10–33. doi:10.2174/157489108783413173 (<https://doi.org/10.2174/157489108783413173>). PMID 18221183 (<https://pubmed.ncbi.nlm.nih.gov/18221183>).
249. Fajardo A, Martínez JL (April 2008). "Antibiotics as signals that trigger specific bacterial responses". *Current Opinion in Microbiology*. **11** (2): 161–7. doi:10.1016/j.mib.2008.02.006 (<https://doi.org/10.1016%2Fj.mib.2008.02.006>). PMID 18373943 (<https://pubmed.ncbi.nlm.nih.gov/18373943>).
250. Loo DS (2006). "Systemic antifungal agents: an update of established and new therapies". *Advances in Dermatology*. **22**: 101–24. doi:10.1016/j.yadr.2006.07.001 (<https://doi.org/10.1016%2Fj.yadr.2006.07.001>). PMID 17249298 (<https://pubmed.ncbi.nlm.nih.gov/17249298>).
251. Manzoni M, Rollini M (April 2002). "Biosynthesis and biotechnological production of statins by filamentous fungi and application of these cholesterol-lowering drugs". *Applied Microbiology and Biotechnology*. **58** (5): 555–64. doi:10.1007/s00253-002-0932-9 (<https://doi.org/10.1007%2Fs00253-002-0932-9>). PMID 11956737 (<https://pubmed.ncbi.nlm.nih.gov/11956737>). S2CID 5761188 (<https://api.semanticscholar.org/CorpusID:5761188>).
252. Daws RE, Timmermann C, Giribaldi B, Sexton JD, Wall MB, Erritzoe D, et al. (April 2022). "Increased global integration in the brain after psilocybin therapy for depression" (<https://doi.org/10.1038%2Fs41591-022-01744-z>). *Nature Medicine*. **28** (4): 844–851. doi:10.1038/s41591-022-01744-z (<https://doi.org/10.1038%2Fs41591-022-01744-z>). hdl:10044/1/95521 (<https://hdl.handle.net/10044%2F1%2F95521>). ISSN 1546-170X (<https://search.worldcat.org/issn/1546-170X>). PMID 35411074 (<https://pubmed.ncbi.nlm.nih.gov/35411074>). S2CID 248099554 (<https://api.semanticscholar.org/CorpusID:248099554>).
253. el-Mekkawy S, Meselhy MR, Nakamura N, Tezuka Y, Hattori M, Kakiuchi N, et al. (November 1998). "Anti-HIV-1 and anti-HIV-1-protease substances from *Ganoderma lucidum*". *Phytochemistry*. **49** (6): 1651–7. Bibcode:1998PChem..49.1651E (<https://ui.adsabs.harvard.edu/abs/1998PChem..49.1651E>). doi:10.1016/S0031-9422(98)00254-4 (<https://doi.org/10.1016%2FS0031-9422%2898%2900254-4>). PMID 9862140 (<https://pubmed.ncbi.nlm.nih.gov/9862140>).
254. El Dine RS, El Halawany AM, Ma CM, Hattori M (June 2008). "Anti-HIV-1 protease activity of lanostane triterpenes from the Vietnamese mushroom *Ganoderma colossum*". *Journal of Natural Products*. **71** (6): 1022–6. Bibcode:2008JNAtP..71.1022E (<https://ui.adsabs.harvard.edu/abs/2008JNAtP..71.1022E>). doi:10.1021/np8001139 (<https://doi.org/10.1021%2Fnp8001139>). PMID 18547117 (<https://pubmed.ncbi.nlm.nih.gov/18547117>).
255. Hetland G, Johnson E, Lyberg T, Bernardshaw S, Tryggestad AM, Grinde B (October 2008). "Effects of the medicinal mushroom *Agaricus blazei* Murill on immunity, infection and cancer" (<https://doi.org/10.1111%2Fj.1365-3083.2008.02156.x>). *Scandinavian Journal of Immunology*. **68** (4): 363–70. doi:10.1111/j.1365-3083.2008.02156.x (<https://doi.org/10.1111%2Fj.1365-3083.2008.02156.x>). PMID 18782264 (<https://pubmed.ncbi.nlm.nih.gov/18782264>). S2CID 3866471 (<https://api.semanticscholar.org/CorpusID:3866471>).
256. Sullivan R, Smith JE, Rowan NJ (2006). "Medicinal mushrooms and cancer therapy: translating a traditional practice into Western medicine". *Perspectives in Biology and Medicine*. **49** (2): 159–70. doi:10.1353/pbm.2006.0034 (<https://doi.org/10.1353%2Fpbm.2006.0034>). PMID 16702701 (<https://pubmed.ncbi.nlm.nih.gov/16702701>). S2CID 29723996 (<https://api.semanticscholar.org/CorpusID:29723996>).
257. Halpern GM, Miller A (2002). *Medicinal Mushrooms: Ancient Remedies for Modern Ailments*. New York, New York: M. Evans and Co. p. 116. ISBN 978-0-87131-981-4.

258. Fritz H, Kennedy DA, Ishii M, Fergusson D, Fernandes R, Cooley K, et al. (2015). "Polysaccharide K and *Coriolus versicolor* extracts for lung cancer" (<https://doi.org/10.1177%2F1534735415572883>). *Integrative Cancer Therapies*. **14** (3): 201–211. doi:10.1177/1534735415572883 (<https://doi.org/10.1177%2F1534735415572883>). PMID 25784670 (<https://pubmed.ncbi.nlm.nih.gov/25784670>).
259. Firenzuoli F, Gori L, Lombardo G (March 2008). "The Medicinal Mushroom *Agaricus blazei* Murrill: Review of Literature and Pharmaco-Toxicological Problems" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2249742>). *Evidence-Based Complementary and Alternative Medicine*. **5** (1): 3–15. doi:10.1093/ecam/nem007 (<https://doi.org/10.1093%2Fecam%2Fhem007>). PMC 2249742 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2249742>). PMID 18317543 (<https://pubmed.ncbi.nlm.nih.gov/18317543>).
260. Lu J, He R, Sun P, Zhang F, Linhardt RJ, Zhang A (2020). "Molecular mechanisms of bioactive polysaccharides from *Ganoderma lucidum* (Lingzhi), a review". *International Journal of Biological Macromolecules*. **150**: 765–774. doi:10.1016/j.ijbiomac.2020.02.035 (<https://doi.org/10.1016/j.ijbiomac.2020.02.035>). PMID 32035956 (<https://pubmed.ncbi.nlm.nih.gov/32035956>). S2CID 211071754 (<https://api.semanticscholar.org/CorpusID:211071754>).
261. Olatunji OJ, Tang J, Tola A, Auberon F, Oluwaniyi O, Ouyang Z (2018). "The genus *Cordyceps*: An extensive review of its traditional uses, phytochemistry and pharmacology". *Fitoterapia*. **129**: 293–316. doi:10.1016/j.fitote.2018.05.010 (<https://doi.org/10.1016%2Fj.fitote.2018.05.010>). PMID 29775778 (<https://pubmed.ncbi.nlm.nih.gov/29775778>). S2CID 21741034 (<https://api.semanticscholar.org/CorpusID:21741034>).
262. Kulp K (2000). *Handbook of Cereal Science and Technology*. CRC Press. ISBN 978-0-8247-8294-8.
263. Piskur J, Rozpedowska E, Polakova S, Merico A, Compagno C (April 2006). "How did *Saccharomyces* evolve to become a good brewer?". *Trends in Genetics*. **22** (4): 183–6. doi:10.1016/j.tig.2006.02.002 (<https://doi.org/10.1016%2Fj.tig.2006.02.002>). PMID 16499989 (<https://pubmed.ncbi.nlm.nih.gov/16499989>).
264. Abe K, Gomi K, Hasegawa F, Machida M (September 2006). "Impact of *Aspergillus oryzae* genomics on industrial production of metabolites". *Mycopathologia*. **162** (3): 143–53. doi:10.1007/s11046-006-0049-2 (<https://doi.org/10.1007%2Fs11046-006-0049-2>). PMID 16944282 (<https://pubmed.ncbi.nlm.nih.gov/16944282>). S2CID 36874528 (<https://api.semanticscholar.org/CorpusID:36874528>).
265. Hachmeister KA, Fung DY (1993). "Tempeh: a mold-modified indigenous fermented food made from soybeans and/or cereal grains". *Critical Reviews in Microbiology*. **19** (3): 137–88. doi:10.3109/10408419309113527 (<https://doi.org/10.3109%2F10408419309113527>). PMID 8267862 (<https://pubmed.ncbi.nlm.nih.gov/8267862>).
266. Jørgensen TR (December 2007). "Identification and toxicogenic potential of the industrially important fungi, *Aspergillus oryzae* and *Aspergillus sojae*" (<https://doi.org/10.4315%2F0362-028X-70.12.2916>). *Journal of Food Protection*. **70** (12): 2916–34. doi:10.4315/0362-028X-70.12.2916 (<https://doi.org/10.4315%2F0362-028X-70.12.2916>). PMID 18095455 (<https://pubmed.ncbi.nlm.nih.gov/18095455>).
267. O'Donnell K, Cigelnik E, Casper HH (February 1998). "Molecular phylogenetic, morphological, and mycotoxin data support reidentification of the Quorn mycoprotein fungus as *Fusarium venenatum*". *Fungal Genetics and Biology*. **23** (1): 57–67. doi:10.1006/fgb.1997.1018 (<https://doi.org/10.1006%2Ffgb.1997.1018>). PMID 9501477 (<https://pubmed.ncbi.nlm.nih.gov/9501477>). S2CID 23049409 (<https://api.semanticscholar.org/CorpusID:23049409>).
268. Stamets P (2000). *Growing Gourmet and Medicinal Mushrooms [Shokuyō oyobi yakuyō kinoko no saibai]*. Berkeley, California: Ten Speed Press. pp. 233–248. ISBN 978-1-58008-175-7.
269. Hall 2003, pp. 13–26.
270. Kinsella JE, Hwang DH (November 1976). "Enzymes of *Penicillium roqueforti* involved in the biosynthesis of cheese flavor". *Critical Reviews in Food Science and Nutrition*. **8** (2): 191–228. doi:10.1080/10408397609527222 (<https://doi.org/10.1080%2F10408397609527222>). PMID 21770 (<https://pubmed.ncbi.nlm.nih.gov/21770>).

271. Erdogan A, Gurses M, Sert S (August 2003). "Isolation of moulds capable of producing mycotoxins from blue mouldy Tulum cheeses produced in Turkey". *International Journal of Food Microbiology*. **85** (1–2): 83–5. doi:10.1016/S0168-1605(02)00485-3 ([https://doi.org/10.1016/S0168-1605\(02\)00485-3](https://doi.org/10.1016/S0168-1605(02)00485-3)). PMID 12810273 (<https://pubmed.ncbi.nlm.nih.gov/12810273/>).
272. Orr DB, Orr RT (1979). *Mushrooms of Western North America*. Berkeley, California: University of California Press. p. 17. ISBN 978-0-520-03656-7.
273. Vetter J (January 1998). "Toxins of *Amanita phalloides*". *Toxicon*. **36** (1): 13–24. Bibcode:1998Txcn...36...13V (<https://ui.adsabs.harvard.edu/abs/1998Txcn...36...13V>). doi:10.1016/S0041-0101(97)00074-3 ([https://doi.org/10.1016/S0041-0101\(97\)00074-3](https://doi.org/10.1016/S0041-0101(97)00074-3)). PMID 9604278 (<https://pubmed.ncbi.nlm.nih.gov/9604278/>).
274. Leathem AM, Dorran TJ (March 2007). "Poisoning due to raw *Gyromitra esculenta* (false morels) west of the Rockies" (<https://doi.org/10.1017%2Fs1481803500014937>). *Canadian Journal of Emergency Medicine*. **9** (2): 127–30. doi:10.1017/s1481803500014937 (<https://doi.org/10.1017/s1481803500014937>). PMID 17391587 (<https://pubmed.ncbi.nlm.nih.gov/17391587/>).
275. Karlson-Stiber C, Persson H (September 2003). "Cytotoxic fungi--an overview". *Toxicon*. **42** (4): 339–49. Bibcode:2003Txcn...42..339K (<https://ui.adsabs.harvard.edu/abs/2003Txcn...42..339K>). doi:10.1016/S0041-0101(03)00238-1 ([https://doi.org/10.1016/S0041-0101\(03\)00238-1](https://doi.org/10.1016/S0041-0101(03)00238-1)). PMID 14505933 (<https://pubmed.ncbi.nlm.nih.gov/14505933/>).
276. Michelot D, Melendez-Howell LM (February 2003). "Amanita muscaria: chemistry, biology, toxicology, and ethnomycology". *Mycological Research*. **107** (Pt 2): 131–46. doi:10.1017/S0953756203007305 (<https://doi.org/10.1017/S0953756203007305>). PMID 12747324 (<https://pubmed.ncbi.nlm.nih.gov/12747324/>). S2CID 41451034 (<https://api.semanticscholar.org/CorpusID:41451034>).
277. Hall 2003, p. 7.
278. Ammirati JF, McKenny M, Stuntz DE (1987). *The New Savory Wild Mushroom*. Seattle, Washington: University of Washington Press. pp. xii–xiii. ISBN 978-0-295-96480-5.
279. López-Gómez J, Molina-Meyer M (February 2006). "The competitive exclusion principle versus biodiversity through competitive segregation and further adaptation to spatial heterogeneities". *Theoretical Population Biology*. **69** (1): 94–109. Bibcode:2006TPBio..69...94L (<https://ui.adsabs.harvard.edu/abs/2006TPBio..69...94L>). doi:10.1016/j.tpb.2005.08.004 (<https://doi.org/10.1016/j.tpb.2005.08.004>). PMID 16223517 (<https://pubmed.ncbi.nlm.nih.gov/16223517/>).
280. Becker H (1998). "Setting the Stage To Screen Biocontrol Fungi" (<https://agresearchmag.ars.usda.gov/1998/jul/fung>). United States Department of Agriculture, Agricultural Research Service. Archived (<https://web.archive.org/web/20090116041447/http://www.ars.usda.gov/is/AR/archive/jul98/fung0798.htm>) from the original on 16 January 2009. Retrieved 23 February 2009.
281. Chandler D (2017). "Basic and Applied Research on Entomopathogenic Fungi". In Lacey LA (ed.). *Microbial Control of Insect and Mite Pests*. Academic Press. pp. 69–89. doi:10.1016/B978-0-12-803527-6.00005-6 (<https://doi.org/10.1016/B978-0-12-803527-6.00005-6>). ISBN 978-0-12-803527-6.
282. Deshpande MV (1999). "Mycopesticide production by fermentation: potential and challenges". *Critical Reviews in Microbiology*. **25** (3): 229–43. doi:10.1080/10408419991299220 (<https://doi.org/10.1080/10408419991299220>). PMID 10524330 (<https://pubmed.ncbi.nlm.nih.gov/10524330/>).
283. Thomas MB, Read AF (May 2007). "Can fungal biopesticides control malaria?". *Nature Reviews Microbiology*. **5** (5): 377–83. doi:10.1038/nrmicro1638 (<https://doi.org/10.1038/nrmicro1638>). hdl:1842/2089 (<https://hdl.handle.net/1842/2089>). PMID 17426726 (<https://pubmed.ncbi.nlm.nih.gov/17426726/>). S2CID 14460348 (<https://api.semanticscholar.org/CorpusID:14460348>).
284. Guerre P (2015). "Ergot alkaloids produced by endophytic fungi of the genus *Epichloë*" (<https://doi.org/10.3390%2Ftoxins7030773>). *Toxins*. **7** (3): 773–790. doi:10.3390/toxins7030773 (<https://doi.org/10.3390%2Ftoxins7030773>). PMC 4379524 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379524>). PMID 25756954 (<https://pubmed.ncbi.nlm.nih.gov/25756954/>).

285. Bouton JH, Latch GC, Hill NS, Hoveland CS, McCann MA, Watson RH, et al. (2002). "Reinfection of Tall Fescue Cultivars with Non-Ergot Alkaloid-Producing Endophytes" (<https://doi.org/10.2134/agronj2002.5670>). *Agronomy Journal*. **94** (3): 567–574. Bibcode:2002AgrJ...94..567B (<https://ui.adsabs.harvard.edu/abs/2002AgrJ...94..567B>). doi:10.2134/agronj2002.5670 (<https://doi.org/10.2134%2Fagronj2002.5670>). Archived (<https://web.archive.org/web/20180721065833/https://dl.sciencesocieties.org/publications/aj/pdfs/94/3/567>) from the original on 21 July 2018. Retrieved 21 May 2020.
286. Parish JA, McCann MA, Watson RH, Hoveland CS, Hawkins LL, Hill NS, et al. (May 2003). "Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in sheep". *Journal of Animal Science*. **81** (5): 1316–22. doi:10.2527/2003.8151316x (<https://doi.org/10.2527/2003.8151316x>). PMID 12772860 (<https://pubmed.ncbi.nlm.nih.gov/12772860>).
287. Zhuo R, Fan F (2021). "A comprehensive insight into the application of white rot fungi and their lignocellulolytic enzymes in the removal of organic pollutants". *Science of the Total Environment*. **778** 146132. Bibcode:2021ScTEn.77846132Z (<https://ui.adsabs.harvard.edu/abs/2021ScTEn.77846132Z>). doi:10.1016/j.scitotenv.2021.146132 (<https://doi.org/10.1016%2Fj.scitotenv.2021.146132>). PMID 33714829 (<https://pubmed.ncbi.nlm.nih.gov/33714829>). S2CID 232230208 (<https://api.semanticscholar.org/CorpusID:232230208>).
288. "Fungi to fight 'toxic war zones'" (http://news.bbc.co.uk/2/hi/uk_news/scotland/tayside_and_central/7384500.stm). BBC News. 5 May 2008. Archived (https://web.archive.org/web/20170915195952/http://news.bbc.co.uk/2/hi/uk_news/scotland/tayside_and_central/7384500.stm) from the original on 15 September 2017. Retrieved 12 May 2008.
289. Fomina M, Charnock JM, Hillier S, Alvarez R, Gadd GM (July 2007). "Fungal transformations of uranium oxides". *Environmental Microbiology*. **9** (7): 1696–710. Bibcode:2007EnvMi...9.1696F (<https://ui.adsabs.harvard.edu/abs/2007EnvMi...9.1696F>). doi:10.1111/j.1462-2920.2007.01288.x (<https://doi.org/10.1111%2Fj.1462-2920.2007.01288.x>). PMID 17564604 (<https://pubmed.ncbi.nlm.nih.gov/17564604>).
290. Fomina M, Charnock JM, Hillier S, Alvarez R, Livens F, Gadd GM (May 2008). "Role of fungi in the biogeochemical fate of depleted uranium" (<https://doi.org/10.1016%2Fj.cub.2008.03.011>). *Current Biology*. **18** (9): R375–7. Bibcode:2008CBio...18.R375F (<https://ui.adsabs.harvard.edu/abs/2008CBio...18.R375F>). doi:10.1016/j.cub.2008.03.011 (<https://doi.org/10.1016%2Fj.cub.2008.03.011>). PMID 18460315 (<https://pubmed.ncbi.nlm.nih.gov/18460315>). S2CID 52805144 (<https://api.semanticscholar.org/CorpusID:52805144>).
291. Beadle GW, Tatum EL (November 1941). "Genetic Control of Biochemical Reactions in *Neurospora*" (<https://doi.org/10.1073%2Fpnas.27.11.499>). *Proceedings of the National Academy of Sciences of the United States of America*. **27** (11): 499–506. Bibcode:1941PNAS...27..499B (<https://ui.adsabs.harvard.edu/abs/1941PNAS...27..499B>). doi:10.1073/pnas.27.11.499 (<https://doi.org/10.1073%2Fpnas.27.11.499>). PMC 1078370 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1078370>). PMID 16588492 (<https://pubmed.ncbi.nlm.nih.gov/16588492>).
292. Datta A, Ganesan K, Natarajan K (1990). "Current Trends in *Candida albicans* Research". *Advances in Microbial Physiology Volume 30*. Vol. 30. Elsevier. pp. 53–88. doi:10.1016/S0065-2911(08)60110-1 (<https://doi.org/10.1016%2FS0065-2911%2808%2960110-1>). ISBN 978-0-12-027730-8. PMID 2700541 (<https://pubmed.ncbi.nlm.nih.gov/2700541>).
293. Dean RA, Talbot NJ, Ebbot DJ, Farman ML, Mitchell TK, Orbach MJ, et al. (April 2005). "The genome sequence of the rice blast fungus *Magnaporthe grisea*" (<https://doi.org/10.1038%2Fnature03449>). *Nature*. **434** (7036): 980–6. Bibcode:2005Natur.434..980D (<https://ui.adsabs.harvard.edu/abs/2005Natur.434..980D>). doi:10.1038/nature03449 (<https://doi.org/10.1038%2Fnature03449>). PMID 15846337 (<https://pubmed.ncbi.nlm.nih.gov/15846337>).
294. Karbalaei M, Rezaee SA, Farsiani H (2020). "Pichia pastoris: A highly successful expression system for optimal synthesis of heterologous proteins" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7228273>). *Journal of Cellular Physiology*. **235** (9): 5867–5881. doi:10.1002/jcp.29583 (<https://doi.org/10.1002%2Fjcp.29583>). PMC 7228273 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7228273>). PMID 32057111 (<https://pubmed.ncbi.nlm.nih.gov/32057111>).
295. Schlegel HG (1993). *General Microbiology*. Cambridge, UK: Cambridge University Press. p. 360. ISBN 978-0-521-43980-0.

296. Joseph B, Ramteke PW, Thomas G (2008). "Cold active microbial lipases: some hot issues and recent developments". *Biotechnology Advances*. **26** (5): 457–70. doi:10.1016/j.biotechadv.2008.05.003 (<https://doi.org/10.1016%2Fj.biotechadv.2008.05.003>). PMID 18571355 (<https://pubmed.ncbi.nlm.nih.gov/18571355>).
297. Kumar R, Singh S, Singh OV (May 2008). "Bioconversion of lignocellulosic biomass: biochemical and molecular perspectives" (<https://doi.org/10.1007%2Fs10295-008-0327-8>). *Journal of Industrial Microbiology & Biotechnology*. **35** (5): 377–91. doi:10.1007/s10295-008-0327-8 (<https://doi.org/10.1007%2Fs10295-008-0327-8>). PMID 18338189 (<https://pubmed.ncbi.nlm.nih.gov/18338189>). S2CID 4830678 (<https://api.semanticscholar.org/CorpusID:4830678>).
298. "Trichoderma spp., including *T. harzianum*, *T. viride*, *T. koningii*, *T. hamatum* and other spp. Deuteromycetes, Moniliales (asexual classification system)" (<https://web.archive.org/web/20110414111846/http://www.biocontrol.entomology.cornell.edu/pathogens/trichoderma.html>). *Biological Control: A Guide to Natural Enemies in North America*. Archived from the original (<https://www.biocontrol.entomology.cornell.edu/pathogens/trichoderma.html>) on 14 April 2011. Retrieved 10 July 2007.
299. Olempska-Bier ZS, Merker RI, Ditto MD, DiNovi MJ (July 2006). "Food-processing enzymes from recombinant microorganisms--a review" (<https://zenodo.org/record/1259499>). *Regulatory Toxicology and Pharmacology*. **45** (2): 144–158. doi:10.1016/j.yrtph.2006.05.001 (<https://doi.org/10.1016%2Fj.yrtph.2006.05.001>). PMID 16769167 (<https://pubmed.ncbi.nlm.nih.gov/16769167>). Archived (<https://web.archive.org/web/20190703164318/https://zenodo.org/record/1259499>) from the original on 3 July 2019. Retrieved 3 July 2019.
300. Polizeli ML, Rizzatti AC, Monti R, Terenzi HF, Jorge JA, Amorim DS (June 2005). "Xylanases from fungi: properties and industrial applications". *Applied Microbiology and Biotechnology*. **67** (5): 577–91. doi:10.1007/s00253-005-1904-7 (<https://doi.org/10.1007%2Fs00253-005-1904-7>). PMID 15944805 (<https://pubmed.ncbi.nlm.nih.gov/15944805>). S2CID 22956 (<https://api.semanticscholar.org/CorpusID:22956>).

Cited literature

- Ainsworth GC (1976). *Introduction to the History of Mycology*. Cambridge, UK: Cambridge University Press. ISBN 978-0-521-11295-6.
- Alexopoulos CJ, Mims CW, Blackwell M (1996). *Introductory Mycology*. John Wiley & Sons. ISBN 978-0-471-52229-4.
- Deacon J (2005). *Fungal Biology*. Cambridge, Massachusetts: Blackwell Publishers. ISBN 978-1-4051-3066-0.
- Hall IR (2003). *Edible and Poisonous Mushrooms of the World*. Portland, Oregon: Timber Press. ISBN 978-0-88192-586-9.
- Hanson JR (2008). *The Chemistry of Fungi*. Royal Society of Chemistry. ISBN 978-0-85404-136-7.
- Jennings DH, Lysek G (1996). *Fungal Biology: Understanding the Fungal Lifestyle*. Guildford, UK: Bios Scientific Publishers Ltd. ISBN 978-1-85996-150-6.
- Kirk PM, Cannon PF, Minter DW, Stalpers JA (2008). *Dictionary of the Fungi* (10th ed.). Wallingford, UK: CAB International. ISBN 978-0-85199-826-8.
- Taylor EL, Taylor TN (1993). *The Biology and Evolution of Fossil Plants*. Englewood Cliffs, New Jersey: Prentice Hall. ISBN 978-0-13-651589-0.

Further reading

-
- Kolbert, Elizabeth, "Spored to Death" (review of Emily Monosson, *Blight: Fungi and the Coming Pandemic*, Norton, 253 pp.; and Alison Pouliot, *Meetings with Remarkable Mushrooms: Forays with Fungi Across Hemispheres*, University of Chicago Press, 278 pp.), *The New York Review*

of Books, vol. LXX, no.14 (21 September 2023), pp. 41–42. "Fungi sicken us and fungi sustain us. In either case, we ignore them at our peril." (p. 42.)

- Seifert, Keith. *The Hidden Kingdom of Fungi*. Greystone Books, 2022. ISBN 978-1771646628.^[1]

External links

- M. C. Cooke (1875), *Fungi: Their Nature and Uses* (<https://www.gutenberg.org/ebooks/30181>), (2009)
 - ---- (1872), *Rust, Smut, Mildew, & Mould* (<https://www.gutenberg.org/ebooks/63416>): An Introduction to the Study of Microscopic Fungi, (2020)
 - Tree of Life web project: *Fungi* (<http://tolweb.org/fungi>) Archived (<https://web.archive.org/web/20210125081408/http://tolweb.org/fungi>) 25 January 2021 at the Wayback Machine
 - Encyclopedia of Life: *Fungus* (<https://www.eol.org/pages/5559>)
 - FUNGI (<https://www.botanical-dermatology-database.info/BotDermFolder/FUNGI.html>) in BoDD – Botanical Dermatology Database (<https://www.botanical-dermatology-database.info/index.html>)
1. Wilkinson A (6 September 2022). "Meet the fungal friends and foes that surround us" (<https://www.sciencenews.org/article/fungi-hidden-kingdom-book-microfungi>). *Science News*.

Retrieved from "<https://en.wikipedia.org/w/index.php?title=Fungus&oldid=1319520930>"