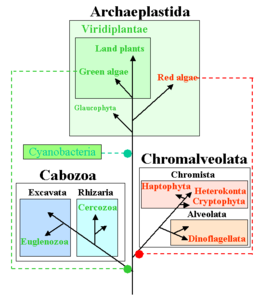
Algae

From Wikipedia, the free encyclopedia

*"Alga" redirects here. For places called Alga, see*[*Alga (disambiguation)*](https://en.wikipedia.org/wiki/Alga_(disambiguation))*. For other uses, see*[*Algae (disambiguation)*](https://en.wikipedia.org/wiki/Algae_(disambiguation))*.*

|  |
| --- |
| **Algae Fossil range: Mesoproterozoic–present**[[1]](https://en.wikipedia.org/wiki/Algae#cite_note-butterfield-1)  [**Had'n**](https://en.wikipedia.org/wiki/Hadean)  [**Archean**](https://en.wikipedia.org/wiki/Archean)  [**Proterozoic**](https://en.wikipedia.org/wiki/Proterozoic)  [**Pha.**](https://en.wikipedia.org/wiki/Phanerozoic) |
| [A variety of algae growing on the sea bed in shallow waters](https://en.wikipedia.org/wiki/File:NSW_seabed_1.JPG)  A variety of algae growing on the sea bed in shallow waters |
| [**Scientific classification**](https://en.wikipedia.org/wiki/Biological_classification) |
| |  |  | | --- | --- | | Domain: | [Eukaryota](https://en.wikipedia.org/wiki/Eukaryota), [Bacteria](https://en.wikipedia.org/wiki/Bacteria) | |
| **Included groups** |
| * [Archaeplastida](https://en.wikipedia.org/wiki/Archaeplastida)   + [Plantae](https://en.wikipedia.org/wiki/Plantae)     - [Chlorophyta](https://en.wikipedia.org/wiki/Chlorophyta) (green algae)     - [Charophyta](https://en.wikipedia.org/wiki/Charophyta) (green algae)   + [Rhodophyta](https://en.wikipedia.org/wiki/Rhodophyta) (red algae)   + [Glaucophyta](https://en.wikipedia.org/wiki/Glaucophyta) * [Rhizaria](https://en.wikipedia.org/wiki/Rhizaria), [Excavata](https://en.wikipedia.org/wiki/Excavata)   + [Chlorarachniophytes](https://en.wikipedia.org/wiki/Chlorarachniophytes)   + [Euglenids](https://en.wikipedia.org/wiki/Euglenids) * [Chromista](https://en.wikipedia.org/wiki/Chromista), [Alveolata](https://en.wikipedia.org/wiki/Alveolata)   + [Heterokonts](https://en.wikipedia.org/wiki/Heterokonts)     - [Bacillariophyceae](https://en.wikipedia.org/wiki/Bacillariophyceae) (Diatoms)     - [Axodines](https://en.wikipedia.org/wiki/Axodine)     - [Bolidomonas](https://en.wikipedia.org/wiki/Bolidomonas)     - [Eustigmatophyceae](https://en.wikipedia.org/wiki/Eustigmatophyceae)     - [Phaeophyceae](https://en.wikipedia.org/wiki/Phaeophyceae) (brown algae)     - [Chrysophyceae](https://en.wikipedia.org/wiki/Chrysophyceae) (golden algae)     - [Raphidophyceae](https://en.wikipedia.org/wiki/Raphidophyceae)     - [Synurophyceae](https://en.wikipedia.org/wiki/Synurophyceae)     - [Xanthophyceae](https://en.wikipedia.org/wiki/Xanthophyceae) (yellow-green algae)   + [Cryptophyta](https://en.wikipedia.org/wiki/Cryptophyta)   + [Dinoflagellata](https://en.wikipedia.org/wiki/Dinoflagellata)   + [Haptophyta](https://en.wikipedia.org/wiki/Haptophyta) * [Cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria) (blue-green algae) |
| **Excluded groups** |
| * [Bacteria](https://en.wikipedia.org/wiki/Bacteria) (non-photosynthetic) * [Protista](https://en.wikipedia.org/wiki/Protist) (non-photosynthetic) * [Animalia](https://en.wikipedia.org/wiki/Animalia) * [Embryophyta](https://en.wikipedia.org/wiki/Embryophyta) * [Fungi](https://en.wikipedia.org/wiki/Fungi) |

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

The lineage of algae according to [Thomas Cavalier-Smith](https://en.wikipedia.org/wiki/Thomas_Cavalier-Smith). The exact number and placement of [endosymbiotic events](https://en.wikipedia.org/wiki/Endosymbiotic_theory) is currently unknown, so this diagram can be taken only as a general guide.[[2]](https://en.wikipedia.org/wiki/Algae#cite_note-keeling-2)[[3]](https://en.wikipedia.org/wiki/Algae#cite_note-parfrey-3) It represents the most parsimonious way of explaining the three types of endosymbiotic origins of plastids. These types include the endosymbiotic events of[cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria), [red algae](https://en.wikipedia.org/wiki/Red_algae) and [green algae](https://en.wikipedia.org/wiki/Green_algae), leading to the hypothesis of the supergroups[Archaeplastida](https://en.wikipedia.org/wiki/Archaeplastida), [Chromalveolata](https://en.wikipedia.org/wiki/Chromalveolata) and [Cabozoa](https://en.wikipedia.org/wiki/Cabozoa)respectively. Endosymbiotic events are noted by dotted lines.

**Algae** ([/ˈældʒi, ˈælɡi/](https://en.wikipedia.org/wiki/Help:IPA_for_English); singular *alga* [/ˈælɡə/](https://en.wikipedia.org/wiki/Help:IPA_for_English)) is an informal term for a large, diverse group of [photosynthetic](https://en.wikipedia.org/wiki/Photosynthesis) [organisms](https://en.wikipedia.org/wiki/Organism)which are not necessarily closely related and are thus [polyphyletic](https://en.wikipedia.org/wiki/Polyphyletic). Included organisms range from [unicellular](https://en.wikipedia.org/wiki/Unicellular) genera, such as [*Chlorella*](https://en.wikipedia.org/wiki/Chlorella) and the [diatoms](https://en.wikipedia.org/wiki/Diatoms), to [multicellular](https://en.wikipedia.org/wiki/Multicellular) forms, such as the [giant kelp](https://en.wikipedia.org/wiki/Macrocystis_pyrifera), a large [brown alga](https://en.wikipedia.org/wiki/Brown_algae) which may grow up to 50 meters in length. Most are aquatic and [autotrophic](https://en.wikipedia.org/wiki/Autotrophic) and lack many of the distinct cell and tissue types, such as[stomata](https://en.wikipedia.org/wiki/Stomata), [xylem](https://en.wikipedia.org/wiki/Xylem) and [phloem](https://en.wikipedia.org/wiki/Phloem), which are found in [land plants](https://en.wikipedia.org/wiki/Embryophyte). The largest and most complex marine algae are called[seaweeds](https://en.wikipedia.org/wiki/Seaweed), while the most complex freshwater forms are the [Charophyta](https://en.wikipedia.org/wiki/Charophyta), a [division](https://en.wikipedia.org/wiki/Phylum) of green algae which includes, for example, [*Spirogyra*](https://en.wikipedia.org/wiki/Spirogyra) and the [stoneworts](https://en.wikipedia.org/wiki/Stonewort).

There is no generally accepted definition of algae. One definition is that algae "have [chlorophyll](https://en.wikipedia.org/wiki/Chlorophyll) as their primary photosynthetic pigment and lack a sterile covering of cells around their reproductive cells".[[4]](https://en.wikipedia.org/wiki/Algae#cite_note-4) Some authors exclude all prokaryotes[[5]](https://en.wikipedia.org/wiki/Algae#cite_note-IntroBot-5) and thus do not consider [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria) (blue-green algae) as algae.[[6]](https://en.wikipedia.org/wiki/Algae#cite_note-Allaby_92-6)

Algae constitute a [polyphyletic](https://en.wikipedia.org/wiki/Polyphyletic) group[[5]](https://en.wikipedia.org/wiki/Algae#cite_note-IntroBot-5) since they do not include a common ancestor, and although their plastids seem to have a single origin, from cyanobacteria,[[2]](https://en.wikipedia.org/wiki/Algae#cite_note-keeling-2) they were acquired in different ways. [Green algae](https://en.wikipedia.org/wiki/Green_algae) are examples of algae that have primary chloroplasts derived from [endosymbiotic](https://en.wikipedia.org/wiki/Endosymbiotic_theory) cyanobacteria. [Diatoms](https://en.wikipedia.org/wiki/Diatoms) and brown algae are examples of algae with secondary chloroplasts derived from an [endosymbiotic](https://en.wikipedia.org/wiki/Endosymbiotic_theory#Secondary_endosymbiosis) [red alga](https://en.wikipedia.org/wiki/Red_alga).[[7]](https://en.wikipedia.org/wiki/Algae#cite_note-7)

Algae exhibit a wide range of reproductive strategies, from simple [asexual](https://en.wikipedia.org/wiki/Asexual_reproduction) cell division to complex forms of [sexual reproduction](https://en.wikipedia.org/wiki/Sexual_reproduction).[[8]](https://en.wikipedia.org/wiki/Algae#cite_note-8)

Algae lack the various structures that characterize land plants, such as the phyllids (leaf-like structures) of [bryophytes](https://en.wikipedia.org/wiki/Bryophytes),[rhizoids](https://en.wikipedia.org/wiki/Rhizoid) in [nonvascular plants](https://en.wikipedia.org/wiki/Nonvascular_plants), and the [roots](https://en.wikipedia.org/wiki/Root), [leaves](https://en.wikipedia.org/wiki/Leaf), and other [organs](https://en.wikipedia.org/wiki/Organ_(anatomy)) that are found in [tracheophytes](https://en.wikipedia.org/wiki/Tracheophyte) ([vascular plants](https://en.wikipedia.org/wiki/Vascular_plants)). Most are [phototrophic](https://en.wikipedia.org/wiki/Phototroph), although some are [mixotrophic](https://en.wikipedia.org/wiki/Mixotroph), deriving energy both from photosynthesis and uptake of organic carbon either by [osmotrophy](https://en.wikipedia.org/wiki/Osmotrophy), [myzotrophy](https://en.wikipedia.org/wiki/Myzocytosis), or [phagotrophy](https://en.wikipedia.org/wiki/Phagocytosis). Some unicellular [species](https://en.wikipedia.org/wiki/Species) of [green algae](https://en.wikipedia.org/wiki/Green_algae), many[golden algae](https://en.wikipedia.org/wiki/Golden_algae), [euglenids](https://en.wikipedia.org/wiki/Euglenids), [dinoflagellates](https://en.wikipedia.org/wiki/Dinoflagellates) and other algae have become [heterotrophs](https://en.wikipedia.org/wiki/Heterotroph) (also called colorless or apochlorotic algae), sometimes parasitic, relying entirely on external energy sources and have limited or no photosynthetic apparatus.[[9]](https://en.wikipedia.org/wiki/Algae#cite_note-9)[[10]](https://en.wikipedia.org/wiki/Algae#cite_note-10)[[11]](https://en.wikipedia.org/wiki/Algae#cite_note-11) Some other heterotrophic organisms, like the [apicomplexans](https://en.wikipedia.org/wiki/Apicomplexans), are also derived from cells whose ancestors possessed plastids, but are not traditionally considered as algae. Algae have photosynthetic machinery ultimately derived from [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria) that produce [oxygen](https://en.wikipedia.org/wiki/Oxygen) as a by-product of photosynthesis, unlike other photosynthetic bacteria such as [purple](https://en.wikipedia.org/wiki/Purple_sulfur_bacteria) and [green sulfur bacteria](https://en.wikipedia.org/wiki/Green_sulfur_bacteria). Fossilized filamentous algae from the [Vindhya](https://en.wikipedia.org/wiki/Vindhya) basin have been dated back to 1.6 to 1.7 billion years ago.[[12]](https://en.wikipedia.org/wiki/Algae#cite_note-12)

## Etymology and study[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=1)]

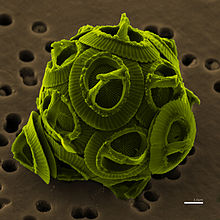
The singular *alga* is the Latin word for "seaweed" and retains that meaning in English.[[13]](https://en.wikipedia.org/wiki/Algae#cite_note-13) The [etymology](https://en.wikipedia.org/wiki/Etymology) is obscure. Although some speculate that it is related to Latin *algēre*, "be cold",[[14]](https://en.wikipedia.org/wiki/Algae#cite_note-14) there is no known reason to associate seaweed with temperature. A more likely source is *alliga*, "binding, entwining."[[15]](https://en.wikipedia.org/wiki/Algae#cite_note-15)

The [Ancient Greek](https://en.wikipedia.org/wiki/Ancient_Greek) word for seaweed was *φῦκος* (fūkos or phykos), which could mean either the seaweed (probably red algae) or a red dye derived from it. The Latinization, *fūcus*, meant primarily the cosmetic rouge. The etymology is uncertain, but a strong candidate has long been some word related to the Biblical *פוך* (pūk), "paint" (if not that word itself), a cosmetic eye-shadow used by the ancient Egyptians and other inhabitants of the eastern Mediterranean. It could be any color: black, red, green, blue.[[16]](https://en.wikipedia.org/wiki/Algae#cite_note-16)

Accordingly, the modern study of marine and freshwater algae is called either [phycology](https://en.wikipedia.org/wiki/Phycology) or algology, depending on whether the Greek or Latin root is used. The name *Fucus* appears in a number of [taxa](https://en.wikipedia.org/wiki/Taxon).

## Classification[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=2)]

*Further information:*[*wikispecies:Algae*](https://species.wikimedia.org/wiki/Algae)

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

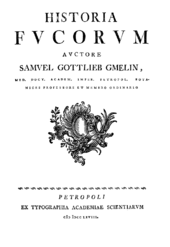
False-color [Scanning electron micrograph](https://en.wikipedia.org/wiki/Scanning_electron_micrograph) of the unicellular[coccolithophore](https://en.wikipedia.org/wiki/Coccolithophore) [*Gephyrocapsa*](https://en.wikipedia.org/wiki/Gephyrocapsa)*oceanica*

Most algae contain [chloroplasts](https://en.wikipedia.org/wiki/Chloroplast) that are similar in structure to [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria). Chloroplasts contain circular [DNA](https://en.wikipedia.org/wiki/DNA) like that in cyanobacteria and presumably represent reduced [endosymbiotic](https://en.wikipedia.org/wiki/Endosymbiotic_theory) cyanobacteria. However, the exact origin of the chloroplasts is different among separate lineages of algae, reflecting their acquisition during different endosymbiotic events. The table below describes the composition of the three major groups of algae. Their lineage relationships are shown in the figure in the upper right. Many of these groups contain some members that are no longer photosynthetic. Some retain plastids, but not chloroplasts, while others have lost plastids entirely.

[Phylogeny](https://en.wikipedia.org/wiki/Phylogeny) based on [plastid](https://en.wikipedia.org/wiki/Plastid)[[17]](https://en.wikipedia.org/wiki/Algae#cite_note-Bhattacharya1998-17) not nucleocytoplasmic genealogy:

|  |  |
| --- | --- |
|  | [Cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria) |
|  |
|  | |  |  | | --- | --- | |  | [Glaucophytes](https://en.wikipedia.org/wiki/Glaucophyte) | |  | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | rhodoplasts | |  |  | | --- | --- | |  | [Rhodophytes](https://en.wikipedia.org/wiki/Rhodophytes) | |  | |  | [Heterokonts](https://en.wikipedia.org/wiki/Heterokonts) | |  | |  | |  |  | | --- | --- | |  | [Cryptophytes](https://en.wikipedia.org/wiki/Cryptomonad) | |  | |  | [Haptophytes](https://en.wikipedia.org/wiki/Haptophytes) | |  | | |  | | |  | | chloroplasts | |  |  | | --- | --- | |  | [Euglenophytes](https://en.wikipedia.org/wiki/Euglenophyte) | |  | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Chlorophytes](https://en.wikipedia.org/wiki/Chlorophyte) | |  | |  | |  |  | | --- | --- | |  | [Charophytes](https://en.wikipedia.org/wiki/Charophyte) | |  | |  | [Land plants (Embryophyta)](https://en.wikipedia.org/wiki/Embryophytes) | |  | | |  | | |  | |  | [Chlorarachniophytes](https://en.wikipedia.org/wiki/Chlorarachniophytes) | |  | | |  | | |  | | |  | |
|  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Supergroup affiliation** | **Members** | [**Endosymbiont**](https://en.wikipedia.org/wiki/Endosymbiont) | **Summary** |
| [Primoplantae](https://en.wikipedia.org/wiki/Primoplantae)/ [Archaeplastida](https://en.wikipedia.org/wiki/Archaeplastida) | * [Chlorophyta](https://en.wikipedia.org/wiki/Chlorophyta) * [Rhodophyta](https://en.wikipedia.org/wiki/Rhodophyta) * [Glaucophyta](https://en.wikipedia.org/wiki/Glaucophyta) | Cyanobacteria | These algae have *primary* [chloroplasts](https://en.wikipedia.org/wiki/Chloroplast), i.e. the chloroplasts are surrounded by *two membranes* and probably developed through a single endosymbiotic event. The chloroplasts of red algae have[chlorophylls](https://en.wikipedia.org/wiki/Chlorophyll) *a* and *c* (often), and [phycobilins](https://en.wikipedia.org/wiki/Phycobilin), while those of green algae have chloroplasts with chlorophyll *a* and *b* without phycobilins. Land plants are pigmented similarly to green algae and probably developed from them, and thus [Chlorophyta](https://en.wikipedia.org/wiki/Chlorophyta) is a sister [taxon](https://en.wikipedia.org/wiki/Taxon) to the plants; sometimes Chlorophyta, [Charophyta](https://en.wikipedia.org/wiki/Charophyta) and land plants are grouped together as [Viridiplantae](https://en.wikipedia.org/wiki/Viridiplantae). |
| [Excavata](https://en.wikipedia.org/wiki/Excavata) and[Rhizaria](https://en.wikipedia.org/wiki/Rhizaria) | * [Chlorarachniophytes](https://en.wikipedia.org/wiki/Chlorarachniophytes) * [Euglenids](https://en.wikipedia.org/wiki/Euglenids) | Green algae | These groups have green chloroplasts containing chlorophylls *a* and *b*.[[18]](https://en.wikipedia.org/wiki/Algae#cite_note-BioRaven-18) Their chloroplasts are surrounded by *four and three membranes* respectively, and were probably retained from ingested green algae.  **Chlorarachniophytes**, which belong to the phylum [Cercozoa](https://en.wikipedia.org/wiki/Cercozoa), contain a small [nucleomorph](https://en.wikipedia.org/wiki/Nucleomorph), which is a [relict](https://en.wikipedia.org/wiki/Relict) of the algae's [nucleus](https://en.wikipedia.org/wiki/Cell_nucleus).  **Euglenids**, which belong to the phylum [Euglenozoa](https://en.wikipedia.org/wiki/Euglenozoa), live primarily in freshwater and have chloroplasts with only three membranes. It has been suggested that the endosymbiotic green algae were acquired through [myzocytosis](https://en.wikipedia.org/wiki/Myzocytosis) rather than [phagocytosis](https://en.wikipedia.org/wiki/Phagocytosis).[[19]](https://en.wikipedia.org/wiki/Algae#cite_note-19) |
| [Chromista](https://en.wikipedia.org/wiki/Chromista) and[Alveolata](https://en.wikipedia.org/wiki/Alveolata) | * [Heterokonts](https://en.wikipedia.org/wiki/Heterokonts) * [Haptophyta](https://en.wikipedia.org/wiki/Haptophyta) * [Cryptomonads](https://en.wikipedia.org/wiki/Cryptomonad) * [Dinoflagellates](https://en.wikipedia.org/wiki/Dinoflagellates) | Red algae | These groups have chloroplasts containing chlorophylls *a* and *c*, and phycobilins. The shape varies from plant to plant; they may be of discoid, plate-like, reticulate, cup-shaped, spiral or ribbon shaped. They have one or more pyrenoids to preserve protein and starch. The latter chlorophyll type is not known from any prokaryotes or primary chloroplasts, but genetic similarities with red algae suggest a relationship there.[[20]](https://en.wikipedia.org/wiki/Algae#cite_note-20)  In the first three of these groups (**Chromista**), the chloroplast has four membranes, retaining a[nucleomorph](https://en.wikipedia.org/wiki/Nucleomorph) in [Cryptomonads](https://en.wikipedia.org/wiki/Cryptomonad), and they likely share a common pigmented ancestor, although other evidence casts doubt on whether the [Heterokonts](https://en.wikipedia.org/wiki/Heterokonts), [Haptophyta](https://en.wikipedia.org/wiki/Haptophyta), and [Cryptomonads](https://en.wikipedia.org/wiki/Cryptomonad) are in fact more closely related to each other than to other groups.[[3]](https://en.wikipedia.org/wiki/Algae#cite_note-parfrey-3)[[21]](https://en.wikipedia.org/wiki/Algae#cite_note-21)  The typical **dinoflagellate** chloroplast has three membranes, but there is considerable diversity in chloroplasts within the group, and it appears that there were a number of endosymbiotic events.[[2]](https://en.wikipedia.org/wiki/Algae#cite_note-keeling-2) The[Apicomplexa](https://en.wikipedia.org/wiki/Apicomplexa), a group of closely related parasites, also have [plastids](https://en.wikipedia.org/wiki/Plastid) called [apicoplasts](https://en.wikipedia.org/wiki/Apicoplast). Apicoplasts are not photosynthetic, but appear to have a common origin with [Dinoflagellate](https://en.wikipedia.org/wiki/Dinoflagellates) chloroplasts.[[2]](https://en.wikipedia.org/wiki/Algae#cite_note-keeling-2) |

[](https://en.wikipedia.org/wiki/File:Gmelin_-_Historia_Fucorum_(Titelblatt).png)

Title page of [Gmelin's](https://en.wikipedia.org/wiki/Samuel_Gottlieb_Gmelin)*Historia Fucorum*, dated 1768

[Linnaeus](https://en.wikipedia.org/wiki/Linnaeus), in [*Species Plantarum*](https://en.wikipedia.org/wiki/Species_Plantarum) (1753),[[22]](https://en.wikipedia.org/wiki/Algae#cite_note-22) the starting point for modern [botanical nomenclature](https://en.wikipedia.org/wiki/Botanical_nomenclature), recognized 14 genera of algae, of which only 4 are currently considered among algae.[[23]](https://en.wikipedia.org/wiki/Algae#cite_note-23) In [*Systema Naturae*](https://en.wikipedia.org/wiki/10th_edition_of_Systema_Naturae), Linnaeus described the genera [*Volvox*](https://en.wikipedia.org/wiki/Volvox), [*Corallina*](https://en.wikipedia.org/wiki/Corallina) and a species of [*Acetabularia*](https://en.wikipedia.org/wiki/Acetabularia) (as [*Madrepora*](https://en.wikipedia.org/wiki/Madrepora)), among the animals.

In 1768, [Samuel Gottlieb Gmelin](https://en.wikipedia.org/wiki/Samuel_Gottlieb_Gmelin) (1744–1774) published the *Historia Fucorum*, the first work dedicated to marine algae and the first book on [marine biology](https://en.wikipedia.org/wiki/Marine_biology) to use the then new [binomial nomenclature](https://en.wikipedia.org/wiki/Binomial_nomenclature) of Linnaeus. It included elaborate illustrations of seaweed and marine algae on folded leaves.[[24]](https://en.wikipedia.org/wiki/Algae#cite_note-24)[[25]](https://en.wikipedia.org/wiki/Algae#cite_note-25)

[W.H.Harvey](https://en.wikipedia.org/wiki/W.H.Harvey) (1811—1866) and [Lamouroux](https://en.wikipedia.org/wiki/Lamouroux) (1813)[[26]](https://en.wikipedia.org/wiki/Algae#cite_note-26) were the first to divide macroscopic algae into four divisions based on their pigmentation. This is the first use of a biochemical criterion in plant systematics. Harvey's four divisions are: red algae (Rhodospermae), brown algae (Melanospermae), green algae (Chlorospermae) and Diatomaceae.[[27]](https://en.wikipedia.org/wiki/Algae#cite_note-Dixon_73-27)[[28]](https://en.wikipedia.org/wiki/Algae#cite_note-28)

At this time, microscopic algae were discovered and reported by a different group of workers (e.g., [O. F. Müller](https://en.wikipedia.org/wiki/Otto_Friedrich_M%C3%BCller) and [Ehrenberg](https://en.wikipedia.org/wiki/Christian_Gottfried_Ehrenberg)) studying the [Infusoria](https://en.wikipedia.org/wiki/Infusoria) (microscopic organisms). Unlike [macroalgae](https://en.wikipedia.org/wiki/Macroalgae), which were clearly viewed as plants, [microalgae](https://en.wikipedia.org/wiki/Microalgae) were frequently considered animals because they are often motile.[[29]](https://en.wikipedia.org/wiki/Algae#cite_note-29) Even the non-motile (coccoid) microalgae were sometimes merely seen as stages of the life cycle of plants, macroalgae or animals.[[30]](https://en.wikipedia.org/wiki/Algae#cite_note-30)[[31]](https://en.wikipedia.org/wiki/Algae#cite_note-31)

Although used as a taxonomic category in some pre-Darwinian classifications, e.g., Linnaeus (1753), de Jussieu (1789), Horaninow (1843), Agassiz (1859), Wilson & Cassin (1864), in further classifications, the "algae" are seen as an artificial, [polyphyletic](https://en.wikipedia.org/wiki/Polyphyletic) group.

Throughout the 20th century, most classifications treated the following groups as divisions or classes of algae: [cyanophytes](https://en.wikipedia.org/wiki/Cyanophyte), [rhodophytes](https://en.wikipedia.org/wiki/Rhodophyte), [chrysophytes](https://en.wikipedia.org/wiki/Chrysophyte),[xanthophytes](https://en.wikipedia.org/wiki/Xanthophyte), [bacillariophytes](https://en.wikipedia.org/wiki/Diatom), [phaeophytes](https://en.wikipedia.org/wiki/Phaeophyte), [pyrrhophytes](https://en.wikipedia.org/wiki/Dinoflagellate#history) ([cryptophytes](https://en.wikipedia.org/wiki/Cryptomonad) and [dinophytes](https://en.wikipedia.org/wiki/Dinophyte)), [euglenophytes](https://en.wikipedia.org/wiki/Euglenophyte) and [chlorophytes](https://en.wikipedia.org/wiki/Chlorophyte). Later, many new groups were discovered (e.g., [Bolidophyceae](https://en.wikipedia.org/wiki/Bolidophyceae)), and others were splintered from older groups: [charophytes](https://en.wikipedia.org/wiki/Charophyte) and [glaucophytes](https://en.wikipedia.org/wiki/Glaucophyte) (from chlorophytes), many [heterokontophytes](https://en.wikipedia.org/wiki/Heterokontophyte) (e.g.,[synurophytes](https://en.wikipedia.org/wiki/Synurophyceae) from chrysophytes, or [eustigmatophytes](https://en.wikipedia.org/wiki/Eustigmatophyte) from xanthophytes), [haptophytes](https://en.wikipedia.org/wiki/Haptophyte) (from chrysophytes) and [chlorarachniophytes](https://en.wikipedia.org/wiki/Chlorarachniophyte) (from xanthophytes).

With the abandonment of plant-animal dichotomous classification, most groups of algae (sometimes all) were included in [Protista](https://en.wikipedia.org/wiki/Protist), later also abandoned in favour of[Eukaryota](https://en.wikipedia.org/wiki/Eukaryota). However, as a legacy of the older plant life scheme, some groups that were also treated as [protozoans](https://en.wikipedia.org/wiki/Protozoa) in the past still have duplicated classifications (see[ambiregnal protists](https://en.wikipedia.org/wiki/Ambiregnal_protist)).

Some parasitic algae (e.g., the green algae [*Prototheca*](https://en.wikipedia.org/wiki/Prototheca) and [*Helicosporidium*](https://en.wikipedia.org/wiki/Helicosporidium), parasites of metazoans, or [*Cephaleuros*](https://en.wikipedia.org/wiki/Cephaleuros), parasites of plants) were originally classified as [fungi](https://en.wikipedia.org/wiki/Fungi), [sporozoans](https://en.wikipedia.org/wiki/Sporozoan) or [protistans](https://en.wikipedia.org/wiki/Protist) of [incertae sedis](https://en.wikipedia.org/wiki/Incertae_sedis),[[32]](https://en.wikipedia.org/wiki/Algae#cite_note-32) while others (e.g., the green algae [*Phyllosiphon*](https://en.wikipedia.org/wiki/Phyllosiphon) and [*Rhodochytrium*](https://en.wikipedia.org/wiki/Rhodochytrium), parasites of plants, or the red algae[*Pterocladiophila*](https://en.wikipedia.org/wiki/Pterocladiophila) and [*Gelidiocolax mammillatus*](https://en.wikipedia.org/w/index.php?title=Gelidiocolax_mammillatus&action=edit&redlink=1), parasites of other red algae, or the dinoflagellates [*Oodinium*](https://en.wikipedia.org/wiki/Oodinium), parasites of fish) had their relationship with algae conjectured early. In other cases, some groups were originally characterized as parasitic algae (e.g., [*Chlorochytrium*](https://en.wikipedia.org/wiki/Chlorochytrium)), but later were seen as [endophytic](https://en.wikipedia.org/wiki/Endophytic) algae.[[33]](https://en.wikipedia.org/wiki/Algae#cite_note-33)Some filamentous bacteria (e.g., [*Beggiatoa*](https://en.wikipedia.org/wiki/Beggiatoa)) were originally seen as algae. Furthermore, groups like the [apicomplexans](https://en.wikipedia.org/wiki/Apicomplexan) are also parasites derived from ancestors that possessed plastids, but are not included in any group traditionally seen as algae.

## Relationship to land plants[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=3)]

The first land plants probably evolved from shallow freshwater [charophyte](https://en.wikipedia.org/wiki/Charophyta) algae much like [*Chara*](https://en.wikipedia.org/wiki/Chara_(alga)) almost 500 million years ago. These probably had an isomorphic[alternation of generations](https://en.wikipedia.org/wiki/Alternation_of_generations) and were probably filamentous. Fossils of isolated land plant spores suggest land plants may have been around as long as 475 million years ago.[[34]](https://en.wikipedia.org/wiki/Algae#cite_note-34)[[35]](https://en.wikipedia.org/wiki/Algae#cite_note-Wellman2003-35)

## Morphology[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=4)]

[](https://en.wikipedia.org/wiki/File:Kelp-forest-Monterey.jpg)

The [kelp forest](https://en.wikipedia.org/wiki/Kelp_forest) exhibit at the Monterey Bay Aquarium. A three-dimensional, multicellular thallus

A range of algal [morphologies](https://en.wikipedia.org/wiki/Morphology_(biology)) is exhibited, and [convergence](https://en.wikipedia.org/wiki/Convergent_evolution) of features in unrelated groups is common. The only groups to exhibit three-dimensional multicellular [thalli](https://en.wikipedia.org/wiki/Thallus) are the [reds](https://en.wikipedia.org/wiki/Red_algae) and [browns](https://en.wikipedia.org/wiki/Brown_algae), and some [chlorophytes](https://en.wikipedia.org/wiki/Chlorophyta).[[36]](https://en.wikipedia.org/wiki/Algae#cite_note-Xiao2004-36) Apical growth is constrained to subsets of these groups: the [florideophyte](https://en.wikipedia.org/wiki/Florideophyceae) reds, various browns, and the charophytes.[[36]](https://en.wikipedia.org/wiki/Algae#cite_note-Xiao2004-36) The form of [charophytes](https://en.wikipedia.org/wiki/Charophyta) is quite different from those of reds and browns, because they have distinct nodes, separated by internode 'stems'; whorls of branches reminiscent of the[horsetails](https://en.wikipedia.org/wiki/Horsetail) occur at the nodes.[[36]](https://en.wikipedia.org/wiki/Algae#cite_note-Xiao2004-36) [Conceptacles](https://en.wikipedia.org/wiki/Conceptacle) are another [polyphyletic](https://en.wikipedia.org/wiki/Polyphyletic) trait; they appear in the [coralline algae](https://en.wikipedia.org/wiki/Coralline_algae) and the[Hildenbrandiales](https://en.wikipedia.org/wiki/Hildenbrandiales), as well as the browns.[[36]](https://en.wikipedia.org/wiki/Algae#cite_note-Xiao2004-36)

Most of the simpler algae are [unicellular](https://en.wikipedia.org/wiki/Unicellular) [flagellates](https://en.wikipedia.org/wiki/Flagellate) or [amoeboids](https://en.wikipedia.org/wiki/Amoeboid), but colonial and non-motile forms have developed independently among several of the groups. Some of the more common organizational levels, more than one of which may occur in the [life cycle](https://en.wikipedia.org/wiki/Biological_life_cycle) of a species, are

* [*Colonial*](https://en.wikipedia.org/wiki/Colony_(biology)): small, regular groups of motile cells
* *Capsoid*: individual non-motile cells embedded in [mucilage](https://en.wikipedia.org/wiki/Mucilage)
* *Coccoid*: individual non-motile cells with cell walls
* *Palmelloid*: non-motile cells embedded in mucilage
* *Filamentous*: a string of non-motile cells connected together, sometimes branching
* *Parenchymatous*: cells forming a [thallus](https://en.wikipedia.org/wiki/Thallus_(tissue)) with partial differentiation of tissues

In three lines, even higher levels of organization have been reached, with full tissue differentiation. These are the [brown algae](https://en.wikipedia.org/wiki/Brown_algae),[[37]](https://en.wikipedia.org/wiki/Algae#cite_note-37)—some of which may reach 50 m in length ([kelps](https://en.wikipedia.org/wiki/Kelp))[[38]](https://en.wikipedia.org/wiki/Algae#cite_note-Thomas_02-38)—the [red algae](https://en.wikipedia.org/wiki/Red_alga),[[39]](https://en.wikipedia.org/wiki/Algae#cite_note-39) and the [green algae](https://en.wikipedia.org/wiki/Green_alga).[[40]](https://en.wikipedia.org/wiki/Algae#cite_note-40) The most complex forms are found among the green algae (see[Charales](https://en.wikipedia.org/wiki/Charales) and [Charophyta](https://en.wikipedia.org/wiki/Charophyta)), in a lineage that eventually led to the higher [land plants](https://en.wikipedia.org/wiki/Land_plants). The point where these non-algal plants begin and algae stop is usually taken to be the presence of reproductive organs with protective cell layers, a characteristic not found in the other alga groups.

## Physiology[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=5)]

Many algae, particularly members of the [Characeae](https://en.wikipedia.org/wiki/Characeae),[[41]](https://en.wikipedia.org/wiki/Algae#cite_note-41) have served as model experimental organisms to understand the mechanisms of the water permeability of membranes, [osmoregulation](https://en.wikipedia.org/wiki/Osmoregulation), [turgor regulation](https://en.wikipedia.org/w/index.php?title=Turgor_regulation&action=edit&redlink=1), [salt tolerance](https://en.wikipedia.org/wiki/Salt_tolerance), [cytoplasmic streaming](https://en.wikipedia.org/wiki/Cytoplasmic_streaming), and the generation of [action potentials](https://en.wikipedia.org/wiki/Action_potentials).

[Phytohormones](https://en.wikipedia.org/wiki/Phytohormone) are found not only in higher plants, but in algae too.[[42]](https://en.wikipedia.org/wiki/Algae#cite_note-42)

## Symbiotic algae[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=6)]

Some species of algae form [symbiotic relationships](https://en.wikipedia.org/wiki/Symbiosis) with other organisms. In these [symbioses](https://en.wikipedia.org/wiki/Symbioses), the algae supply photosynthates (organic substances) to the host organism providing protection to the algal cells. The host organism derives some or all of its energy requirements from the algae. Examples are as follows.

### Lichens[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=7)]

*Main article:*[*Lichens*](https://en.wikipedia.org/wiki/Lichens)

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

Rock lichens in Ireland

[*Lichens*](https://en.wikipedia.org/wiki/Lichen) are defined by the [International Association for Lichenology](https://en.wikipedia.org/wiki/International_Association_for_Lichenology) to be "an association of a fungus and a photosynthetic[symbiont](https://en.wikipedia.org/wiki/Symbiont) resulting in a stable vegetative body having a specific structure."[[43]](https://en.wikipedia.org/wiki/Algae#cite_note-43) The fungi, or mycobionts, are mainly from the[Ascomycota](https://en.wikipedia.org/wiki/Ascomycota) with a few from the [Basidiomycota](https://en.wikipedia.org/wiki/Basidiomycota). They are not found alone in nature; but when they began to associate is not known.[[44]](https://en.wikipedia.org/wiki/Algae#cite_note-44) One mycobiont associates with the same phycobiont species, rarely two, from the [green algae](https://en.wikipedia.org/wiki/Green_algae), except that alternatively the mycobiont may associate with a species of [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria) (hence "photobiont" is the more accurate term). A photobiont may be associated with many different mycobionts or may live independently; accordingly, lichens are named and classified as fungal species.[[45]](https://en.wikipedia.org/wiki/Algae#cite_note-45) The association is termed a morphogenesis because the lichen has a form and capabilities not possessed by the symbiont species alone (they can be experimentally isolated). It is possible that the photobiont triggers otherwise latent genes in the mycobiont.[[46]](https://en.wikipedia.org/wiki/Algae#cite_note-46)

### Coral reefs[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=8)]

*Main articles:*[*Coral*](https://en.wikipedia.org/wiki/Coral)*,*[*Coral reef*](https://en.wikipedia.org/wiki/Coral_reef)*, and*[*Symbiodinium*](https://en.wikipedia.org/wiki/Symbiodinium)

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

Floridian coral reef

[Coral reefs](https://en.wikipedia.org/wiki/Coral_reef) are accumulated from the [calcareous](https://en.wikipedia.org/wiki/Calcareous) [exoskeletons](https://en.wikipedia.org/wiki/Exoskeleton) of [marine invertebrates](https://en.wikipedia.org/wiki/Marine_invertebrate) of the order [Scleractinia](https://en.wikipedia.org/wiki/Scleractinia) (stony[corals](https://en.wikipedia.org/wiki/Coral)). These [animals](https://en.wikipedia.org/wiki/Animal#Food_and_energy_sourcing) [metabolize](https://en.wikipedia.org/wiki/Metabolism) [sugar](https://en.wikipedia.org/wiki/Sugar#Chemistry) and [oxygen](https://en.wikipedia.org/wiki/Oxygen) to obtain energy for their cell-building processes, including [secretion](https://en.wikipedia.org/wiki/Secretion) of the exoskeleton, with water and [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) as byproducts. [Dinoflagellates](https://en.wikipedia.org/wiki/Dinoflagellate) (algal [protists](https://en.wikipedia.org/wiki/Protist)) are often [endosymbionts](https://en.wikipedia.org/wiki/Endosymbiont) in the cells of the coral-forming marine invertebrates, where they accelerate host-cell metabolism by generating immediately available sugar and oxygen through [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis) using incident light and the carbon dioxide produced by the host. Reef-building stony corals ([hermatypic corals](https://en.wikipedia.org/wiki/Hermatypic_coral)) require [endosymbiotic](https://en.wikipedia.org/wiki/Endosymbiont) algae from the genus [*Symbiodinium*](https://en.wikipedia.org/wiki/Symbiodinium) to be in a healthy condition.[[47]](https://en.wikipedia.org/wiki/Algae#cite_note-47) The loss of *Symbiodinium* from the host is known as [coral bleaching](https://en.wikipedia.org/wiki/Coral_bleaching), a condition which leads to the deterioration of a reef.

### Sea sponges[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=9)]

*Main article:*[*Sea sponge*](https://en.wikipedia.org/wiki/Sea_sponge)

Green algae live close to the surface of some sponges, for example, breadcrumb sponge ([*Halichondria panicea*](https://en.wikipedia.org/wiki/Halichondria_panicea)). The alga is thus protected from predators; the sponge is provided with oxygen and sugars which can account for 50 to 80% of sponge growth in some species.[[48]](https://en.wikipedia.org/wiki/Algae#cite_note-48)

## Life-cycle[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=10)]

[Rhodophyta](https://en.wikipedia.org/wiki/Rhodophyta), [Chlorophyta](https://en.wikipedia.org/wiki/Chlorophyta) and [Heterokontophyta](https://en.wikipedia.org/wiki/Heterokontophyta), the three main algal [divisions](https://en.wikipedia.org/wiki/Phylum), have life-cycles which show considerable variation and complexity. In general, there is an asexual phase where the seaweed's cells are [diploid](https://en.wikipedia.org/wiki/Diploid), a sexual phase where the cells are [haploid](https://en.wikipedia.org/wiki/Haploid) followed by fusion of the male and female [gametes](https://en.wikipedia.org/wiki/Gametes). Asexual reproduction permits efficient population increases, but less variation is possible. Commonly, in sexual reproduction of unicellular and colonial algae, two specialized sexually compatible haploid gametes make physical contact and fuse to form a [zygote](https://en.wikipedia.org/wiki/Zygote). To ensure a successful mating, the development and release of gametes is highly synchronized and regulated; pheromones may play a key role in these processes.[[49]](https://en.wikipedia.org/wiki/Algae#cite_note-pmid24597605-49) Sexual reproduction allows for more variation and provides the benefit of efficient recombinational repair of DNA damages during meiosis, a key stage of the sexual cycle.[[50]](https://en.wikipedia.org/wiki/Algae#cite_note-50) However, sexual reproduction is more costly than asexual reproduction.[[51]](https://en.wikipedia.org/wiki/Algae#cite_note-pmid19441962-51) Meiosis has been shown to occur in many different species of algae.[[52]](https://en.wikipedia.org/wiki/Algae#cite_note-pmid773364-52)

*For more details on this topic, see*[*Conceptacle*](https://en.wikipedia.org/wiki/Conceptacle)*.*

## Numbers[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=11)]

[](https://en.wikipedia.org/wiki/File:Taiwan_2009_East_Coast_ShihTiPing_Giant_Stone_Steps_Algae_FRD_6581.jpg)

Algae on coastal rocks at [Shihtiping](https://zh.wikipedia.org/wiki/%E7%9F%B3%E6%A2%AF%E5%9D%AA)in Taiwan

The *Algal Collection of the US National Herbarium* (located in the [National Museum of Natural History](https://en.wikipedia.org/wiki/National_Museum_of_Natural_History)) consists of approximately 320,500 dried specimens, which, although not exhaustive (no exhaustive collection exists), gives an idea of the order of magnitude of the number of algal species (that number remains unknown).[[53]](https://en.wikipedia.org/wiki/Algae#cite_note-53) Estimates vary widely. For example, according to one standard textbook,[[54]](https://en.wikipedia.org/wiki/Algae#cite_note-John_02-54) in the British Isles the *UK Biodiversity Steering Group Report* estimated there to be 20000 algal species in the UK. Another checklist reports only about 5000 species. Regarding the difference of about 15000 species, the text concludes: "It will require many detailed field surveys before it is possible to provide a reliable estimate of the total number of species ..."

Regional and group estimates have been made as well:

* 5000–5500 species of red algae worldwide
* "some 1300 in Australian Seas"[[55]](https://en.wikipedia.org/wiki/Algae#cite_note-Huisman_00-55)
* 400 seaweed species for the western coastline of South Africa,[[56]](https://en.wikipedia.org/wiki/Algae#cite_note-Stegenga_97-56) and 212 species from the coast of KwaZulu-Natal.[[57]](https://en.wikipedia.org/wiki/Algae#cite_note-57) Some of these are duplicates, as the range extends across both coasts, and the total recorded is probably about 500 species. Most of these are listed in [List of seaweeds of South Africa](https://en.wikipedia.org/wiki/List_of_seaweeds_of_South_Africa). These exclude [phytoplankton](https://en.wikipedia.org/wiki/Phytoplankton) and crustose corallines.
* 669 marine species from California (US)[[58]](https://en.wikipedia.org/wiki/Algae#cite_note-Abbott_and_Hollenberg_76-58)
* 642 in the check-list of Britain and Ireland[[59]](https://en.wikipedia.org/wiki/Algae#cite_note-Hardy_nad_Guiry_06-59)

and so on, but lacking any scientific basis or reliable sources, these numbers have no more credibility than the British ones mentioned above. Most estimates also omit microscopic algae, such as phytoplankton.

The most recent estimate suggests 72,500 algal species worldwide.[[60]](https://en.wikipedia.org/wiki/Algae#cite_note-60)

## Distribution[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=12)]

The distribution of algal species has been fairly well studied since the founding of [phytogeography](https://en.wikipedia.org/wiki/Phytogeography) in the mid-19th century AD.[[61]](https://en.wikipedia.org/wiki/Algae#cite_note-Round8-61) Algae spread mainly by the dispersal of [spores](https://en.wikipedia.org/wiki/Spore) analogously to the dispersal of Plantae by seeds and spores. This dispersal can be accomplished by air, water, or other organisms. Due to this, spores can be found in a variety of environments: fresh and marine waters, air, soil, and in or on other organisms.[[61]](https://en.wikipedia.org/wiki/Algae#cite_note-Round8-61) Whether a spore is to grow into an organism depends on the combination of the species and the environmental conditions of where the spore lands.

The spores of fresh-water algae are dispersed mainly by running water and wind, as well as by living carriers.[[61]](https://en.wikipedia.org/wiki/Algae#cite_note-Round8-61) However, not all bodies of water can carry all species of algae, as the chemical composition of certain water bodies will limit the algae that can survive within it.[[61]](https://en.wikipedia.org/wiki/Algae#cite_note-Round8-61) Marine spores are often spread by ocean currents. Ocean water presents many vastly-different habitats based on temperature and nutrient-availability, resulting in phytogeographic zones, regions and provinces.[[62]](https://en.wikipedia.org/wiki/Algae#cite_note-62)

To some degree, the distribution of algae is subject to floristic discontinuities caused by geographical features, such as [Antarctica](https://en.wikipedia.org/wiki/Antarctica), long distances of ocean or general land masses. It is therefore possible to identify species occurring by locality, such as "Pacific Algae" or "North Sea Algae". When they occur out of their localities, it is usually possible to hypothesize a transport mechanism, such as the hulls of ships. For example, *Ulva reticulata* and *Ulva fasciata* travelled from the mainland to Hawaii in this manner.

Mapping is possible for select species only: "there are many valid examples of confined distribution patterns."[[63]](https://en.wikipedia.org/wiki/Algae#cite_note-63) For example, *Clathromorphum* is an arctic genus and is not mapped far south of there.[[64]](https://en.wikipedia.org/wiki/Algae#cite_note-64) On the other hand, scientists regard the overall data as insufficient due to the "difficulties of undertaking such studies."[[65]](https://en.wikipedia.org/wiki/Algae#cite_note-65)

## Ecology[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=13)]

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

Phytoplankton, [Lake Chuzenji](https://en.wikipedia.org/wiki/Lake_Chuzenji)

Algae are prominent in bodies of water, common in terrestrial environments and are found in unusual environments, such as[on snow](https://en.wikipedia.org/wiki/Snow_algae) and [on ice](https://en.wikipedia.org/wiki/Ice_algae). Seaweeds grow mostly in shallow marine waters, under 100 metres (330 ft); however, some have been recorded to a depth of 360 metres (1,180 ft).[[66]](https://en.wikipedia.org/wiki/Algae#cite_note-66)

The various sorts of algae play significant roles in aquatic ecology. Microscopic forms that live suspended in the water column ([phytoplankton](https://en.wikipedia.org/wiki/Phytoplankton)) provide the food base for most marine [food chains](https://en.wikipedia.org/wiki/Food_chain). In very high densities ([algal blooms](https://en.wikipedia.org/wiki/Algal_bloom)) these algae may discolor the water and outcompete, poison, or [asphyxiate](https://en.wikipedia.org/wiki/Asphyxiate) other life forms.

Algae can be used as [indicator organisms](https://en.wikipedia.org/wiki/Indicator_organism) to monitor pollution in various aquatic systems.[[67]](https://en.wikipedia.org/wiki/Algae#cite_note-Omar2010-67) In many cases, algal [metabolism](https://en.wikipedia.org/wiki/Metabolism)is sensitive to various pollutants. Due to this, the species composition of algal populations may shift in the presence of chemical pollutants.[[67]](https://en.wikipedia.org/wiki/Algae#cite_note-Omar2010-67) To detect these changes, algae can be sampled from the environment and maintained in laboratories with relative ease.[[67]](https://en.wikipedia.org/wiki/Algae#cite_note-Omar2010-67)

On the basis of their habitat, algae can be categorized as: [aquatic](https://en.wikipedia.org/wiki/Aquatic_plant) ([planktonic](https://en.wikipedia.org/wiki/Planktonic), [benthic](https://en.wikipedia.org/wiki/Benthic), [marine](https://en.wikipedia.org/wiki/Marine_biology), [freshwater](https://en.wikipedia.org/wiki/Freshwater)), [terrestrial](https://en.wikipedia.org/wiki/Terrestrial_plant), [aerial](https://en.wikipedia.org/wiki/Aerobiology) (subareial),[[68]](https://en.wikipedia.org/wiki/Algae#cite_note-68) [lithophytic](https://en.wikipedia.org/wiki/Lithophytic), [halophytic](https://en.wikipedia.org/wiki/Halophytic) (or[euryhaline](https://en.wikipedia.org/wiki/Euryhaline)), [psammon](https://en.wikipedia.org/wiki/Psammon), [thermophilic](https://en.wikipedia.org/wiki/Thermophilic), [cryophilic](https://en.wikipedia.org/wiki/Psychrophile), [epibiont](https://en.wikipedia.org/wiki/Epibiont) ([epiphytic](https://en.wikipedia.org/wiki/Epiphytic), [epizoic](https://en.wikipedia.org/wiki/Epizoic)), [endosymbiont](https://en.wikipedia.org/wiki/Endosymbiont) ([endophytic](https://en.wikipedia.org/wiki/Endophytic), endozoic), [parasitic](https://en.wikipedia.org/wiki/Parasitic), [calcifilic](https://en.wikipedia.org/wiki/Calcareous) or [lichenic](https://en.wikipedia.org/wiki/Lichen) (phycobiont).[[69]](https://en.wikipedia.org/wiki/Algae#cite_note-69)

## Cultural associations[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=14)]

In [Classical Chinese](https://en.wikipedia.org/wiki/Classical_Chinese), the word [藻](https://en.wiktionary.org/wiki/%E8%97%BB) is used both for "algae" and (in the modest tradition of the [imperial scholars](https://en.wikipedia.org/wiki/Scholar-official)) for "literary talent". The third island in [Kunming Lake](https://en.wikipedia.org/wiki/Kunming_Lake)beside the [Summer Palace](https://en.wikipedia.org/wiki/Summer_Palace) in Beijing is known as the Zaojian Tang Dao which thus simultaneously means "Island of the Algae-Viewing Hall" and "Island of the Hall for Reflecting on Literary Talent".

## Uses[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=15)]

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

Harvesting algae

### Agar[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=16)]

[Agar](https://en.wikipedia.org/wiki/Agar), a [gelatinous](https://en.wikipedia.org/wiki/Gelatin) substance derived from [red algae](https://en.wikipedia.org/wiki/Red_algae), has a number of commercial uses.[[70]](https://en.wikipedia.org/wiki/Algae#cite_note-Lewis_.27.27et_al..27.27_88-70) It is a good medium on which to grow bacteria and fungi as most microorganisms cannot digest agar.

### Alginates[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=17)]

Alginic acid, or alginate, is extracted from brown algae. Its uses range from gelling agents in food, to medical dressings. Alginic acid also has been used in the field of [biotechnology](https://en.wikipedia.org/wiki/Biotechnology) as a biocompatible medium for cell encapsulation and cell immobilization. [Molecular cuisine](https://en.wikipedia.org/wiki/Molecular_cuisine) is also a user of the substance for its gelling properties, by which it becomes a delivery vehicle for flavours.

Between 100,000 and 170,000 wet tons of [*Macrocystis*](https://en.wikipedia.org/wiki/Macrocystis) are harvested annually in [New Mexico](https://en.wikipedia.org/wiki/New_Mexico) for [alginate](https://en.wikipedia.org/wiki/Alginic_acid) extraction and [abalone](https://en.wikipedia.org/wiki/Abalone) feed.[[71]](https://en.wikipedia.org/wiki/Algae#cite_note-71)[[72]](https://en.wikipedia.org/wiki/Algae#cite_note-72)

### Energy source[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=18)]

*Main articles:*[*Algae fuel*](https://en.wikipedia.org/wiki/Algae_fuel)*,*[*Biological hydrogen production*](https://en.wikipedia.org/wiki/Biological_hydrogen_production)*,*[*Biohydrogen*](https://en.wikipedia.org/wiki/Biohydrogen)*,*[*Biodiesel*](https://en.wikipedia.org/wiki/Biodiesel)*,*[*Ethanol fuel*](https://en.wikipedia.org/wiki/Ethanol_fuel)*,*[*Butanol fuel*](https://en.wikipedia.org/wiki/Butanol_fuel)*, and*[*Vegetable oil*](https://en.wikipedia.org/wiki/Vegetable_oil)

To be competitive and independent from fluctuating support from (local) policy on the long run, biofuels should equal or beat the cost level of fossil fuels. Here, algae based fuels hold great promise,[[73]](https://en.wikipedia.org/wiki/Algae#cite_note-73)[[74]](https://en.wikipedia.org/wiki/Algae#cite_note-74) directly related to the potential to produce more biomass per unit area in a year than any other form of biomass. The break-even point for algae-based biofuels is estimated to occur by 2025.[[75]](https://en.wikipedia.org/wiki/Algae#cite_note-75)

### Fertilizer[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=19)]

*For more details on this topic, see*[*Seaweed fertiliser*](https://en.wikipedia.org/wiki/Seaweed_fertiliser)*.*

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

Seaweed-fertilized gardens on[Inisheer](https://en.wikipedia.org/wiki/Inisheer)

For centuries, seaweed has been used as a fertilizer; [George Owen of Henllys](https://en.wikipedia.org/wiki/George_Owen_of_Henllys) writing in the 16th century referring to drift weed in [South Wales](https://en.wikipedia.org/wiki/South_Wales):[[76]](https://en.wikipedia.org/wiki/Algae#cite_note-76)

This kind of ore they often gather and lay on great heapes, where it heteth and rotteth, and will have a strong and loathsome smell; when being so rotten they cast on the land, as they do their muck, and thereof springeth good corn, especially barley ... After spring-tydes or great rigs of the sea, they fetch it in sacks on horse backes, and carie the same three, four, or five miles, and cast it on the lande, which doth very much better the ground for corn and grass.

Today, algae are used by humans in many ways; for example, as [fertilizers](https://en.wikipedia.org/wiki/Fertilizer), [soil conditioners](https://en.wikipedia.org/wiki/Soil_conditioner) and livestock feed.[[77]](https://en.wikipedia.org/wiki/Algae#cite_note-77) Aquatic and microscopic species are cultured in clear tanks or ponds and are either harvested or used to treat effluents pumped through the ponds. [Algaculture](https://en.wikipedia.org/wiki/Algaculture) on a large scale is an important type of [aquaculture](https://en.wikipedia.org/wiki/Aquaculture) in some places. [Maerl](https://en.wikipedia.org/wiki/Maerl) is commonly used as a soil conditioner.

### Nutrition[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=20)]

*See also:*[*Edible seaweed*](https://en.wikipedia.org/wiki/Edible_seaweed)

[](https://en.wikipedia.org/wiki/File:Dulse.JPG)

Dulse, a type of food

Naturally growing seaweeds are an important source of food, especially in Asia. They provide many vitamins including: A, [B1](https://en.wikipedia.org/wiki/Thiamine), [B2](https://en.wikipedia.org/wiki/Riboflavin),[B6](https://en.wikipedia.org/wiki/Vitamin_B6), [niacin](https://en.wikipedia.org/wiki/Niacin) and [C](https://en.wikipedia.org/wiki/Vitamin_C), and are rich in [iodine](https://en.wikipedia.org/wiki/Iodine), [potassium](https://en.wikipedia.org/wiki/Potassium), iron, [magnesium](https://en.wikipedia.org/wiki/Magnesium) and [calcium](https://en.wikipedia.org/wiki/Calcium).[[78]](https://en.wikipedia.org/wiki/Algae#cite_note-78) In addition commercially cultivated[microalgae](https://en.wikipedia.org/wiki/Microphyte), including both algae and [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria), are marketed as nutritional supplements, such as [Spirulina](https://en.wikipedia.org/wiki/Spirulina_(dietary_supplement)),[[79]](https://en.wikipedia.org/wiki/Algae#cite_note-79) [Chlorella](https://en.wikipedia.org/wiki/Chlorella)and the Vitamin-C supplement, [Dunaliella](https://en.wikipedia.org/wiki/Dunaliella), high in [beta-carotene](https://en.wikipedia.org/wiki/Beta-carotene).

Algae are national foods of many nations: China consumes more than 70 species, including [*fat choy*](https://en.wikipedia.org/wiki/Fat_choy_(vegetable)), a [cyanobacterium](https://en.wikipedia.org/wiki/Cyanobacterium)considered a vegetable; Japan, over 20 species;[[80]](https://en.wikipedia.org/wiki/Algae#cite_note-Mondragon_03-80) Ireland, [dulse](https://en.wikipedia.org/wiki/Dulse); [Chile](https://en.wikipedia.org/wiki/Chile), [cochayuyo](https://en.wikipedia.org/wiki/Cochayuyo).[[81]](https://en.wikipedia.org/wiki/Algae#cite_note-81) [Laver](https://en.wikipedia.org/wiki/Laver_(seaweed)) is used to make "laver bread" in[Wales](https://en.wikipedia.org/wiki/Wales) where it is known as *bara lawr*; in [Korea](https://en.wikipedia.org/wiki/Korea), [gim](https://en.wikipedia.org/wiki/Gim_(Korean_food)); in Japan, [nori](https://en.wikipedia.org/wiki/Nori) and [aonori](https://en.wikipedia.org/wiki/Aonori). It is also used along the west coast of North America from California to [British Columbia](https://en.wikipedia.org/wiki/British_Columbia), in Hawaii and by the [Māori](https://en.wikipedia.org/wiki/M%C4%81ori_people) of [New Zealand](https://en.wikipedia.org/wiki/New_Zealand). [Sea lettuce](https://en.wikipedia.org/wiki/Sea_lettuce) and [badderlocks](https://en.wikipedia.org/wiki/Alaria_esculenta) are a salad ingredient in [Scotland](https://en.wikipedia.org/wiki/Scotland), Ireland, [Greenland](https://en.wikipedia.org/wiki/Greenland) and [Iceland](https://en.wikipedia.org/wiki/Iceland).

The oils from some algae have high levels of [unsaturated fatty acids](https://en.wikipedia.org/wiki/Unsaturated_fatty_acid). For example, [*Parietochloris incisa*](https://en.wikipedia.org/wiki/Parietochloris_incisa) is very high in[arachidonic acid](https://en.wikipedia.org/wiki/Arachidonic_acid), where it reaches up to 47% of the triglyceride pool.[[82]](https://en.wikipedia.org/wiki/Algae#cite_note-82) Some varieties of algae favored by vegetarianism and[veganism](https://en.wikipedia.org/wiki/Veganism) contain the long-chain, essential [omega-3 fatty acids](https://en.wikipedia.org/wiki/Omega-3_fatty_acid), [docosahexaenoic acid](https://en.wikipedia.org/wiki/Docosahexaenoic_acid) (DHA) and [eicosapentaenoic acid](https://en.wikipedia.org/wiki/Eicosapentaenoic_acid) (EPA). Fish oil contains the omega-3 fatty acids, but the original source is algae ([microalgae](https://en.wikipedia.org/wiki/Microalgae) in particular), which are eaten by marine life such as [copepods](https://en.wikipedia.org/wiki/Copepod) and are passed up the food chain.[[83]](https://en.wikipedia.org/wiki/Algae#cite_note-83) Algae have emerged in recent years as a popular source of [omega-3 fatty acids](https://en.wikipedia.org/wiki/Omega-3_fatty_acid) for vegetarians who cannot get long-chain EPA and DHA from other vegetarian sources such as [flaxseed oil](https://en.wikipedia.org/wiki/Flaxseed_oil), which only contains the short-chain [alpha-linolenic acid](https://en.wikipedia.org/wiki/Alpha-linolenic_acid) (ALA).

### Pollution control[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=21)]

* Sewage can be treated with algae, reducing the usage of large amounts of toxic chemicals that would otherwise be needed.
* Algae can be used to capture [fertilizers](https://en.wikipedia.org/wiki/Fertilizers) in runoff from farms. When subsequently harvested, the enriched algae itself can be used as fertilizer.
* Aquariums and ponds can be filtered using algae, which absorb nutrients from the water in a device called an [algae scrubber](https://en.wikipedia.org/wiki/Algae_scrubber), also known as an algae turf scrubber (A T S) .[[84]](https://en.wikipedia.org/wiki/Algae#cite_note-84)[[85]](https://en.wikipedia.org/wiki/Algae#cite_note-85)[[86]](https://en.wikipedia.org/wiki/Algae#cite_note-86)[[87]](https://en.wikipedia.org/wiki/Algae#cite_note-87)

[Agricultural Research Service](https://en.wikipedia.org/wiki/Agricultural_Research_Service) scientists found that 60–90% of nitrogen runoff and 70–100% of phosphorus runoff can be captured from [manure effluents](https://en.wikipedia.org/w/index.php?title=Manure_effluents&action=edit&redlink=1) using a horizontal algae scrubber, also called an [algal turf scrubber](https://en.wikipedia.org/wiki/Algal_turf_scrubber) (ATS). Scientists developed the ATS, which consists of shallow, 100-foot raceways of nylon netting where algae colonies can form, and studied its efficacy for three years. They found that algae can readily be used to reduce the nutrient runoff from agricultural fields and increase the quality of water flowing into rivers, streams, and oceans. Researchers collected and dried the nutrient-rich algae from the ATS and studied its potential as an organic fertilizer. They found that cucumber and corn seedlings grew just as well using ATS organic fertilizer as they did with commercial fertilizers.[[88]](https://en.wikipedia.org/wiki/Algae#cite_note-88) Algae scrubbers, using bubbling upflow or vertical waterfall versions, are now also being used to filter aquariums and ponds.

### Bioremediation[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=22)]

The alga [*Stichococcus bacillaris*](https://en.wikipedia.org/w/index.php?title=Stichococcus_bacillaris&action=edit&redlink=1), has been seen to colonize silicone resins used at archaeological sites; [biodegrading](https://en.wikipedia.org/wiki/Biodegradation) the synthetic substance.[[89]](https://en.wikipedia.org/wiki/Algae#cite_note-89)

### Pigments[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=23)]

The natural [pigments](https://en.wikipedia.org/wiki/Pigment) ([carotenoids](https://en.wikipedia.org/wiki/Carotenoid) and [chlorophylls](https://en.wikipedia.org/wiki/Chlorophylls)) produced by algae can be used as an alternative to chemical [dyes](https://en.wikipedia.org/wiki/Dyes) and coloring agents.[[90]](https://en.wikipedia.org/wiki/Algae#cite_note-90) The presence of some individual alga pigments, together with specific pigment concentrations ratios, are taxon-specific: analysis of their concentrations with various analytical methods, particularly [high-performance liquid chromatography](https://en.wikipedia.org/wiki/High-performance_liquid_chromatography) (HPLC), can therefore offer deep insight into the taxonomic composition and relative abundance of natural alga populations in sea water samples.[[91]](https://en.wikipedia.org/wiki/Algae#cite_note-91)[[92]](https://en.wikipedia.org/wiki/Algae#cite_note-92)

### Stabilizing substances[[edit](https://en.wikipedia.org/w/index.php?title=Algae&action=edit&section=24)]

*Main articles:*[*Carrageenan*](https://en.wikipedia.org/wiki/Carrageenan)*and*[*Chondrus crispus*](https://en.wikipedia.org/wiki/Chondrus_crispus)

Carrageenan, from the red alga *Chondrus crispus*, is used as a stabilizer in milk product

Protozoaz

[](https://en.wikipedia.org/wiki/File:Mikrofoto.de-Blepharisma_japonicum_15.jpg)

[*Blepharisma japonicum*](https://en.wikipedia.org/wiki/Blepharisma_japonicum), a free-living [ciliated](https://en.wikipedia.org/wiki/Ciliate)protozoan.

[](https://en.wikipedia.org/wiki/File:Giardia_muris_trophozoite_SEM_11643.jpg)

[*Giardia muris*](https://en.wikipedia.org/w/index.php?title=Giardia_muris&action=edit&redlink=1), a [flagellate](https://en.wikipedia.org/wiki/Flagellate) protozoan, is an intestinal [parasite](https://en.wikipedia.org/wiki/Parasite) found in rodents, birds and reptiles.

[](https://en.wikipedia.org/wiki/File:Collection_P%C3%A9nard_MHNG_Specimen_88-4-4.tif)

[*Centropyxis aculeata*](https://en.wikipedia.org/w/index.php?title=Centropyxis_aculeata&action=edit&redlink=1), a testate (shelled) [amoeba](https://en.wikipedia.org/wiki/Amoeba)

In some systems of [biological classification](https://en.wikipedia.org/wiki/Taxonomy_(biology)), the **Protozoa** are a diverse group of [unicellular](https://en.wikipedia.org/wiki/Unicellular_organism) [eukaryotic](https://en.wikipedia.org/wiki/Eukaryotic)organisms.[[1]](https://en.wikipedia.org/wiki/Protozoa#cite_note-AlcamoWarner2009-1) Historically, **protozoa** were defined as single-celled organisms with [animal](https://en.wikipedia.org/wiki/Animal)-like behaviors, such as[motility](https://en.wikipedia.org/wiki/Motility) and [predation](https://en.wikipedia.org/wiki/Predation). The group was regarded as the zoological counterpart to the "[protophyta](https://en.wikipedia.org/wiki/Protophyta)", which were considered to be plant-like, as they are capable of [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis).[[2]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:3-2) The terms *protozoa* and *protozoans* are also used informally to designate single-celled, non-[photosynthetic](https://en.wikipedia.org/wiki/Photosynthesis) [protists](https://en.wikipedia.org/wiki/Protist), such as [ciliates](https://en.wikipedia.org/wiki/Ciliate), [amoebae](https://en.wikipedia.org/wiki/Amoeba) and[flagellates](https://en.wikipedia.org/wiki/Flagellate).

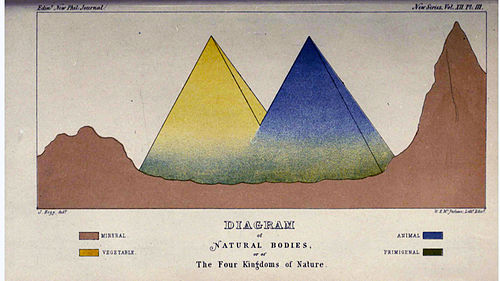
The term Protozoa was introduced in 1818 for a [taxonomic](https://en.wikipedia.org/wiki/Taxonomy_(biology)) [class](https://en.wikipedia.org/wiki/Class_(biology)),[[3]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:2-3) but in later classification schemes the group was elevated to higher ranks, including [phylum](https://en.wikipedia.org/wiki/Phylum_(biology)), [subkingdom](https://en.wikipedia.org/wiki/Subkingdom_(biology)) and [kingdom](https://en.wikipedia.org/wiki/Kingdom_(biology)). In several classification systems proposed by [Thomas Cavalier-Smith](https://en.wikipedia.org/wiki/Thomas_Cavalier-Smith) and his collaborators since 1981, Protozoa is ranked as a kingdom.[[4]](https://en.wikipedia.org/wiki/Protozoa#cite_note-4)[[5]](https://en.wikipedia.org/wiki/Protozoa#cite_note-5)[[6]](https://en.wikipedia.org/wiki/Protozoa#cite_note-6)The seven-kingdom scheme proposed by Ruggiero et al. in 2015, places eight phyla under Protozoa:[Euglenozoa](https://en.wikipedia.org/wiki/Euglenozoa), [Amoebozoa](https://en.wikipedia.org/wiki/Amoebozoa), [Metamonada](https://en.wikipedia.org/wiki/Metamonada), [Choanozoa](https://en.wikipedia.org/wiki/Choanozoa), [Loukozoa](https://en.wikipedia.org/wiki/Loukozoa), [Percolozoa](https://en.wikipedia.org/wiki/Percolozoa), [Microsporidia](https://en.wikipedia.org/wiki/Microsporidia) and [Sulcozoa](https://en.wikipedia.org/w/index.php?title=Sulcozoa&action=edit&redlink=1).[[2]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:3-2) This kingdom does not form a [clade](https://en.wikipedia.org/wiki/Clade), but an [evolutionary grade](https://en.wikipedia.org/wiki/Evolutionary_grade) or [paraphyletic](https://en.wikipedia.org/wiki/Paraphyly) group, from which the fungi and animals are specifically excluded.

The use of Protozoa as a formal [taxon](https://en.wikipedia.org/wiki/Taxon) has been discouraged by some researchers, mainly because the term, which is formed from the Greek *protos* "first" + *zoia*, plural of *zoion*, "animal", misleadingly implies kinship with animals (metazoa)[[7]](https://en.wikipedia.org/wiki/Protozoa#cite_note-7)[[8]](https://en.wikipedia.org/wiki/Protozoa#cite_note-8) and promotes an arbitrary separation of "animal-like" from "plant-like" organisms.[[9]](https://en.wikipedia.org/wiki/Protozoa#cite_note-9)Modern ultrastructural, biochemical, and genetic techniques have shown that protozoa, as traditionally defined, belong to widely divergent lineages, and can no longer be regarded as "primitive animals." For this reason, the terms "protists," "Protista" or "Protoctista" are sometimes preferred for the high-level classification of [eukaryotic](https://en.wikipedia.org/wiki/Eukaryote)microbes. In 2005, members of the Society of [Protozoologists](https://en.wikipedia.org/wiki/Protozoologist) voted to change the name of that organization to the International Society of [Protistologists](https://en.wikipedia.org/wiki/Protistologist)

## History and terminology[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=1)]

The word "protozoa" (singular *protozoon* or *protozoan*) was coined in 1818 by zoologist [Georg August Goldfuss](https://en.wikipedia.org/wiki/Georg_August_Goldfuss), as the Greek equivalent of the German *Urthiere*, meaning "primitive, or original animals" ([*ur-*](https://en.wiktionary.org/wiki/ur-) ‘proto-’ + [*Thier*](https://en.wiktionary.org/wiki/Thier) ‘animal’). Goldfuss erected Protozoa as a [class](https://en.wikipedia.org/wiki/Class_(biology)) containing what he believed to be the simplest animals. Originally, the group included not only [microbes](https://en.wikipedia.org/wiki/Microbes), but also some "lower" multicellular animals, such as [rotifers](https://en.wikipedia.org/wiki/Rotifer), [corals](https://en.wikipedia.org/wiki/Coral), [sponges](https://en.wikipedia.org/wiki/Sponge), [jellyfish](https://en.wikipedia.org/wiki/Jellyfish), [bryozoa](https://en.wikipedia.org/wiki/Bryozoa) and [polychaete worms](https://en.wikipedia.org/wiki/Polychaete).[[3]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:2-3)

In 1848, in light of advancements in [cell theory](https://en.wikipedia.org/wiki/Cell_theory) pioneered by [Theodore Schwann](https://en.wikipedia.org/wiki/Theodor_Schwann) and [Matthias Schleiden](https://en.wikipedia.org/wiki/Matthias_Jakob_Schleiden), the anatomist and zoologist [C.T. von Siebold](https://en.wikipedia.org/wiki/Karl_Theodor_Ernst_von_Siebold) proposed that the bodies of microbial organisms such as [ciliates](https://en.wikipedia.org/wiki/Ciliate) and [amoebae](https://en.wikipedia.org/wiki/Amoeba) were made up of single cells, similar to those from which the multicellular tissues of plants and animals were constructed. Von Siebold redefined Protozoa to include only such [unicellular](https://en.wikipedia.org/wiki/Unicellular_organism) forms, to the exclusion of all metazoa.[[11]](https://en.wikipedia.org/wiki/Protozoa#cite_note-11) At the same time, he raised the group to the level of a [phylum](https://en.wikipedia.org/wiki/Phylum) containing two broad classes of microbes: [Infusoria](https://en.wikipedia.org/wiki/Infusoria) (mostly ciliates and flagellated algae), and Rhizopoda ([amoeboid organisms](https://en.wikipedia.org/wiki/Amoeba)). The definition of Protozoa as a phylum or sub-kingdom made up of "unicellular animals" was adopted by the zoologist [Otto Bütschli](https://en.wikipedia.org/wiki/Otto_B%C3%BCtschli)—celebrated at his centenary as the "architect of protozoology"[[12]](https://en.wikipedia.org/wiki/Protozoa#cite_note-12)—and the term came into wide use.

[](https://en.wikipedia.org/wiki/File:John_Hogg_--_Primigenum_or_Protoctista.jpg)

[John Hogg](https://en.wikipedia.org/wiki/John_Hogg_(biologist))'s illustration of the Four Kingdoms of Nature, showing "Primigenal" as a greenish haze at the base of the Animals and Plants, 1860

As a phylum under Animalia, the Protozoa were firmly rooted in the old "two-kingdom" classification of life, according to which all living beings were classified as either animals or plants. As long as this scheme remained dominant, the protozoa were understood to be animals and studied in departments of Zoology, while photosynthetic microbes and microscopic fungi—the so-called Protophyta—were assigned to the Plants, and studied in departments of Botany.[[13]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:0-13)

Criticism of this system began in the latter half of the 19th century, with the realization that many organisms met the criteria for inclusion among both plants and animals. For example, the algae [*Euglena*](https://en.wikipedia.org/wiki/Euglena) and [*Dinobryon*](https://en.wikipedia.org/wiki/Dinobryon) have [chloroplasts](https://en.wikipedia.org/wiki/Chloroplast)for [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis), but can also feed on organic matter and are [motile](https://en.wikipedia.org/wiki/Motility). In 1860,[John Hogg](https://en.wikipedia.org/wiki/John_Hogg_(biologist)) argued against the use of "protozoa", on the grounds that "naturalists are divided in opinion—and probably some will ever continue so—whether many of these organisms, or living beings, are animals or plants." [[14]](https://en.wikipedia.org/wiki/Protozoa#cite_note-14) As an alternative, he proposed a new kingdom called Primigenum, consisting of both the protozoa and unicellular algae (protophyta), which he combined together under the name "Protoctista". In Hoggs's conception, the animal and plant kingdoms were likened to two great "pyramids" blending at their bases in the Kingdom Primigenum.

Six years later, [Ernst Haeckel](https://en.wikipedia.org/wiki/Ernst_Haeckel) also proposed a third kingdom of life, which he named [Protista](https://en.wikipedia.org/wiki/Protista). At first, Haeckel included a few multicellular organisms in this kingdom, but in later work he restricted the Protista to single-celled organisms, or simple colonies whose individual cells are not differentiated into different kinds of [tissues](https://en.wikipedia.org/wiki/Tissue_(biology)).

Despite these proposals, Protozoa emerged as the preferred taxonomic placement for [heterotrophic](https://en.wikipedia.org/wiki/Heterotrophic_nutrition) microbes such as amoebae and ciliates, and remained so for more than a century. In the course of the 20th century, however, the old "two kingdom" system began to weaken, with the growing awareness that fungi did not belong among the plants, and that most of the unicellular protozoa were no more closely related to the animals than they were to the plants. By mid-century, some biologists, such as [Herbert Copeland](https://en.wikipedia.org/wiki/Herbert_Copeland), [Robert H. Whittaker](https://en.wikipedia.org/wiki/Robert_H._Whittaker) and [Lynn Margulis](https://en.wikipedia.org/wiki/Lynn_Margulis), advocated the revival of Haeckel's Protista or Hogg's Protoctista as a kingdom-level eukaryotic group, alongside Plants, Animals and Fungi.[[13]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:0-13) A variety of [multi-kingdom systems](https://en.wikipedia.org/wiki/Kingdom_(biology)) were proposed, and Kingdoms Protista and Protoctista became well established in biology texts and curricula.[[15]](https://en.wikipedia.org/wiki/Protozoa#cite_note-15)[[16]](https://en.wikipedia.org/wiki/Protozoa#cite_note-16)[[17]](https://en.wikipedia.org/wiki/Protozoa#cite_note-17)

While many taxonomists have abandoned Protozoa as a high-level group, Thomas Cavalier-Smith has retained it as a kingdom in the various classifications he has proposed. As of 2015, Cavalier-Smith's Protozoa excludes several major groups of organisms traditionally placed among the protozoa, including the ciliates,[dinoflagellates](https://en.wikipedia.org/wiki/Dinoflagellate) and [foraminifera](https://en.wikipedia.org/wiki/Foraminifera) (all members of the [SAR supergroup](https://en.wikipedia.org/wiki/SAR_supergroup)). In its current form, his kingdom Protozoa is a [paraphyletic](https://en.wikipedia.org/wiki/Paraphyly) group which includes a common ancestor and most of its descendents, but excludes two important clades that branch within it: the animals and fungi.[[18]](https://en.wikipedia.org/wiki/Protozoa#cite_note-:1-18)

## Characteristics[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=2)]

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

Resting cyst of ciliated protozoan *Dileptus viridis*.

Protozoa, as traditionally defined, are mainly [microscopic](https://en.wikipedia.org/wiki/Microscopic_scale) organisms, ranging in size from 10 to 52 [micrometers](https://en.wikipedia.org/wiki/Micrometers). Some, however, are significantly larger. Among the largest are the deep-sea–dwelling [xenophyophores](https://en.wikipedia.org/wiki/Xenophyophores), single-celled foraminifera whose shells can reach 20 cm in diameter.[[19]](https://en.wikipedia.org/wiki/Protozoa#cite_note-19) Free-living forms are restricted to moist environments, such as soils, mosses and aquatic habitats, although many form [resting cysts](https://en.wikipedia.org/wiki/Microbial_cyst) which enable them to survive drying. Many protozoan species are [symbionts](https://en.wikipedia.org/wiki/Symbiosis), some are [parasites](https://en.wikipedia.org/wiki/Parasites), and some are predators of bacteria, [algae](https://en.wikipedia.org/wiki/Algae) and other protists.

### Motility and feeding[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=3)]

Organisms traditionally classified as protozoa are abundant in [aqueous](https://en.wikipedia.org/wiki/Aqueous) environments and [soil](https://en.wikipedia.org/wiki/Soil), occupying a range of [trophic levels](https://en.wikipedia.org/wiki/Trophic_level). The group includes [flagellates](https://en.wikipedia.org/wiki/Flagellate) (which move with the help of whip-like structures called[flagella](https://en.wikipedia.org/wiki/Flagella)), [ciliates](https://en.wikipedia.org/wiki/Ciliate) (which move by using hair-like structures called [cilia](https://en.wikipedia.org/wiki/Cilia)) and [amoebae](https://en.wikipedia.org/wiki/Amoeba) (which move by the use of foot-like structures called [pseudopodia](https://en.wikipedia.org/wiki/Pseudopodia)). Some protozoa are [sessile](https://en.wikipedia.org/wiki/Sessility_(zoology)), and do not move at all.

Protozoa may take in food by [osmotrophy](https://en.wikipedia.org/wiki/Osmotrophy), absorbing nutrients through their [cell membranes](https://en.wikipedia.org/wiki/Cell_membrane); or they may feed by [phagocytosis](https://en.wikipedia.org/wiki/Phagocytosis), either by engulfing particles of food with pseudopodia (as amoebae do), or taking in food through a mouth-like aperture called a [cytostome](https://en.wikipedia.org/wiki/Cytostome). All protozoa digest their food in stomach-like compartments called [vacuoles](https://en.wikipedia.org/wiki/Vacuoles).[[20]](https://en.wikipedia.org/wiki/Protozoa#cite_note-20)

### Pellicle[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=4)]

The pellicle is a thin layer supporting the [cell membrane](https://en.wikipedia.org/wiki/Cell_membrane) in various protozoa, such as ciliates, protecting them and allowing them to retain their shape, especially during locomotion, allowing the organism to be more [hydrodynamic](https://en.wikipedia.org/wiki/Hydrodynamic). The pellicle varies from flexible and elastic to rigid. Although somewhat stiff, the pellicle is also flexible and allows the [protist](https://en.wikipedia.org/wiki/Protist) to fit into tighter spaces. In [ciliates](https://en.wikipedia.org/wiki/Ciliate) and [Apicomplexa](https://en.wikipedia.org/wiki/Apicomplexa), it is formed from closely packed vesicles called alveoli. In [euglenids](https://en.wikipedia.org/wiki/Euglenid), it is formed from [protein](https://en.wikipedia.org/wiki/Protein) strips arranged spirally along the length of the body. Familiar examples of protists with a pellicle are the [euglenoids](https://en.wikipedia.org/wiki/Euglenoids) and the ciliate [*Paramecium*](https://en.wikipedia.org/wiki/Paramecium). In some protozoa, the pellicle hosts [epibiotic](https://en.wikipedia.org/wiki/Epibiont) bacteria that adhere to the surface by their [fimbriae](https://en.wikipedia.org/wiki/Pilus#fimbriae) (attachment pili).[[21]](https://en.wikipedia.org/wiki/Protozoa#cite_note-21)

### Life cycle[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=5)]

Some protozoa have life phases alternating between proliferative stages (e.g., [trophozoites](https://en.wikipedia.org/wiki/Trophozoite)) and dormant [cysts](https://en.wikipedia.org/wiki/Microbial_cyst). As cysts, protozoa can survive harsh conditions, such as exposure to extreme temperatures or harmful chemicals, or long periods without access to nutrients, water, or oxygen for a period of time. Being a cyst enables parasitic species to survive outside of a host, and allows their transmission from one host to another. When protozoa are in the form of [trophozoites](https://en.wikipedia.org/wiki/Trophozoite) (Greek*tropho* = to nourish), they actively feed. The conversion of a trophozoite to cyst form is known as encystation, while the process of transforming back into a trophozoite is known as excystation. Protozoa reproduce asexually by [binary fission](https://en.wikipedia.org/wiki/Binary_fission) or multiple fission. Many protozoan species exchange genetic material by sexual means (typically, through [conjugation](https://en.wikipedia.org/wiki/Isogamy)); however, sexuality is generally decoupled from the process of reproduction, and does not immediately result in increased population.[[22]](https://en.wikipedia.org/wiki/Protozoa#cite_note-22)

## Classification

The classification of protozoa has been and remains a problematic area of taxonomy. Where they are available, DNA sequences are used as the basis for classification; however, for the majority of described protozoa, such material is not available. They have been and still are mostly on the basis of their morphology and for the parasitic species their hosts.[[*clarification needed*](https://en.wikipedia.org/wiki/Wikipedia:Please_clarify)] Protozoa have been divided traditionally[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] on the basis of their means of locomotion.

* [Flagellates](https://en.wikipedia.org/wiki/Flagellate) (e.g., [*Giardia lamblia*](https://en.wikipedia.org/wiki/Giardia_lamblia))
* [Amoeboids](https://en.wikipedia.org/wiki/Amoeboid) (e.g., [*Entamoeba histolytica*](https://en.wikipedia.org/wiki/Entamoeba_histolytica))
* [Sporozoans](https://en.wikipedia.org/wiki/Sporozoans) (e.g., [*Plasmodium knowlesi*](https://en.wikipedia.org/wiki/Plasmodium_knowlesi))
  + [Apicomplexa](https://en.wikipedia.org/wiki/Apicomplexa) (now in [Alveolata](https://en.wikipedia.org/wiki/Alveolata))
  + [Microsporidia](https://en.wikipedia.org/wiki/Microsporidia) (now in [Fungi](https://en.wikipedia.org/wiki/Fungi))
  + [Ascetosporea](https://en.wikipedia.org/wiki/Ascetosporea) (now in [Rhizaria](https://en.wikipedia.org/wiki/Rhizaria))
  + [Myxosporidia](https://en.wikipedia.org/wiki/Myxosporidia) (now in [Cnidaria](https://en.wikipedia.org/wiki/Cnidaria))
* [Ciliates](https://en.wikipedia.org/wiki/Ciliate) (e.g., [*Balantidium coli*](https://en.wikipedia.org/wiki/Balantidium_coli))

As a phylum the Protozoa were, historically, divided into four subphyla[[23]](https://en.wikipedia.org/wiki/Protozoa#cite_note-23) reflecting the means of locomotion:

* Subphylum [Sarcomastigophora](https://en.wikipedia.org/wiki/Sarcomastigophora)
  + Superclass [Mastigophora](https://en.wikipedia.org/wiki/Mastigophora) (includes flagellates)
  + Superclass [Sarcodina](https://en.wikipedia.org/wiki/Sarcodina)
  + Superclass [Opalinata](https://en.wikipedia.org/wiki/Opalinata)
* Subphylum [Sporozoa](https://en.wikipedia.org/wiki/Sporozoa) (includes apicomplexans)
* Subphylum [Cnidospora](https://en.wikipedia.org/wiki/Cnidospora)
  + Class [Microsporidea](https://en.wikipedia.org/wiki/Microsporidea)
* Subphylum [Ciliophora](https://en.wikipedia.org/wiki/Ciliophora) (includes ciliates)

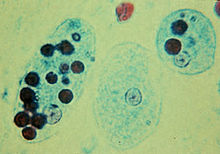
These systems are no longer considered to be valid.

## Ecological role[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=7)]

As components of the [micro-](https://en.wikipedia.org/wiki/Fauna_(animals)#Microfauna) and [meiofauna](https://en.wikipedia.org/wiki/Fauna_(animals)#Meiofauna), protozoa are an important food source for [microinvertebrates](https://en.wikipedia.org/wiki/Microinvertebrate). Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive [trophic levels](https://en.wikipedia.org/wiki/Trophic_pyramid) is important. As predators, they prey upon [unicellular](https://en.wikipedia.org/wiki/Unicellular) or [filamentous algae](https://en.wikipedia.org/wiki/Filamentous_algae), [bacteria](https://en.wikipedia.org/wiki/Bacteria), and [microfungi](https://en.wikipedia.org/wiki/Microfungi). Protozoan species include both [herbivores](https://en.wikipedia.org/wiki/Herbivore) and [consumers](https://en.wikipedia.org/wiki/Heterotroph) in the decomposer link of the [food chain](https://en.wikipedia.org/wiki/Food_chain). They also control bacteria populations and [biomass](https://en.wikipedia.org/wiki/Biomass) to some extent. On average, protozoa eat ~ 100 to 1,000 bacteria per hour.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] Protozoa can stimulate decomposition of organic matter, digest [cellulose](https://en.wikipedia.org/wiki/Cellulose) in the[rumen](https://en.wikipedia.org/wiki/Rumen) of cows and termite guts, and can play a role in nutrient mobilization.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

### Disease

#### In humans

[](https://en.wikipedia.org/wiki/File:Trophozoites_of_Entamoeba_histolytica_with_ingested_erythrocytes.JPG)

Trophozoites of the [amoebic dysentery](https://en.wikipedia.org/wiki/Amoebic_dysentery) pathogen [*Entamoeba histolytica*](https://en.wikipedia.org/wiki/Entamoeba_histolytica) with ingested human [red blood cells](https://en.wikipedia.org/wiki/Red_blood_cell) (dark circles)

*Main article:*[*Protozoan infection*](https://en.wikipedia.org/wiki/Protozoan_infection)

A number of protozoan [pathogens](https://en.wikipedia.org/wiki/Pathogen) are [human parasites](https://en.wikipedia.org/wiki/Human_parasite), causing diseases such as [malaria](https://en.wikipedia.org/wiki/Malaria) (by [*Plasmodium*](https://en.wikipedia.org/wiki/Plasmodium)), [amoebiasis](https://en.wikipedia.org/wiki/Amoebiasis),[giardiasis](https://en.wikipedia.org/wiki/Giardiasis), [toxoplasmosis](https://en.wikipedia.org/wiki/Toxoplasmosis), [cryptosporidiosis](https://en.wikipedia.org/wiki/Cryptosporidiosis), [trichomoniasis](https://en.wikipedia.org/wiki/Trichomoniasis), [Chagas disease](https://en.wikipedia.org/wiki/Chagas_disease), [leishmaniasis](https://en.wikipedia.org/wiki/Leishmaniasis), [African trypanosomiasis](https://en.wikipedia.org/wiki/African_trypanosomiasis)(sleeping sickness), [amoebic dysentery](https://en.wikipedia.org/wiki/Amoebic_dysentery), [acanthamoeba keratitis](https://en.wikipedia.org/wiki/Acanthamoeba_keratitis), and [primary amoebic meningoencephalitis](https://en.wikipedia.org/wiki/Primary_amoebic_meningoencephalitis) (naegleriasis).

#### In other animals[[edit](https://en.wikipedia.org/w/index.php?title=Protozoa&action=edit&section=10)]

The protozoan [*Ophryocystis elektroscirrha*](https://en.wikipedia.org/wiki/Ophryocystis_elektroscirrha) is a parasite of butterfly [larvae](https://en.wikipedia.org/wiki/Larva), passed from [female to caterpillar](https://en.wikipedia.org/wiki/Vertical_transmission). Severely infected individuals are weak, unable to expand their wings, or unable to [eclose](https://en.wikipedia.org/wiki/Eclosion), and have shortened lifespans, but parasite levels vary in populations. Infection creates a [culling](https://en.wikipedia.org/wiki/Culling) effect, whereby infected migrating animals are less likely to complete the migration. This results in populations with lower parasite loads at the end of the migration.[[24]](https://en.wikipedia.org/wiki/Protozoa#cite_note-Bartel_Ober-24) This is not the case in laboratory or commercial rearing, where after a few generations, all individuals can be infected.[[25]](https://en.wikipedia.org/wiki/Protozoa#cite_note-25)

## General Concepts

### Protozoa

Protozoa are one-celled animals found worldwide in most habitats. Most species are free living, but all higher animals are infected with one or more species of protozoa. Infections range from asymptomatic to life threatening, depending on the species and strain of the parasite and the resistance of the host.

### Structure

### Protozoa are microscopic unicellular eukaryotes that have a relatively complex internal structure and carry out complex metabolic activities. Some protozoa have structures for propulsion or other types of movement.

### Classification

On the basis of light and electron microscopic morphology, the protozoa are currently classified into six phyla. Most species causing human disease are members of the phyla Sacromastigophora and Apicomplexa.

### Life Cycle Stages

The stages of parasitic protozoa that actively feed and multiply are frequently called trophozoites; in some protozoa, other terms are used for these stages. Cysts are stages with a protective membrane or thickened wall. Protozoan cysts that must survive outside the host usually have more resistant walls than cysts that form in tissues.

### Reproduction

Binary fission, the most common form of reproduction, is asexual; multiple asexual division occurs in some forms. Both sexual and asexual reproduction occur in the Apicomplexa.

### Nutrition

All parasitic protozoa require preformed organic substances—that is, nutrition is holozoic as in higher animals.

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Introduction

The Protozoa are considered to be a subkingdom of the kingdom Protista, although in the classical system they were placed in the kingdom Animalia. More than 50,000 species have been described, most of which are free-living organisms; protozoa are found in almost every possible habitat. The fossil record in the form of shells in sedimentary rocks shows that protozoa were present in the Pre-cambrian era. Anton van Leeuwenhoek was the first person to see protozoa, using microscopes he constructed with simple lenses. Between 1674 and 1716, he described, in addition to free-living protozoa, several parasitic species from animals, and *Giardia lamblia* from his own stools. Virtually all humans have protozoa living in or on their body at some time, and many persons are infected with one or more species throughout their life. Some species are considered commensals, i.e., normally not harmful, whereas others are pathogens and usually produce disease. Protozoan diseases range from very mild to life-threatening. Individuals whose defenses are able to control but not eliminate a parasitic infection become carriers and constitute a source of infection for others. In geographic areas of high prevalence, well-tolerated infections are often not treated to eradicate the parasite because eradication would lower the individual's immunity to the parasite and result in a high likelihood of reinfection.

Many protozoan infections that are inapparent or mild in normal individuals can be life-threatening in immunosuppressed patients, particularly patients with acquired immune deficiency syndrome (AIDS). Evidence suggests that many healthy persons harbor low numbers of *Pneumocystis carinii* in their lungs. However, this parasite produces a frequently fatal pneumonia in immunosuppressed patients such as those with AIDS. *Toxoplasma gondii,* a very common protozoan parasite, usually causes a rather mild initial illness followed by a long-lasting latent infection. AIDS patients, however, can develop fatal toxoplasmic encephalitis. *Cryptosporidium* was described in the 19th century, but widespread human infection has only recently been recognized. *Cryptosporidium* is another protozoan that can produce serious complications in patients with AIDS. Microsporidiosis in humans was reported in only a few instances prior to the appearance of AIDS. It has now become a more common infection in AIDS patients. As more thorough studies of patients with AIDS are made, it is likely that other rare or unusual protozoan infections will be diagnosed.

*Acanthamoeba* species are free-living amebas that inhabit soil and water. Cyst stages can be airborne. Serious eye-threatening corneal ulcers due to *Acanthamoeba* species are being reported in individuals who use contact lenses. The parasites presumably are transmitted in contaminated lens-cleaning solution. Amebas of the genus *Naegleria*, which inhabit bodies of fresh water, are responsible for almost all cases of the usually fatal disease primary amebic meningoencephalitis. The amebas are thought to enter the body from water that is splashed onto the upper nasal tract during swimming or diving. Human infections of this type were predicted before they were recognized and reported, based on laboratory studies of Acanthamoeba infections in cell cultures and in animals.

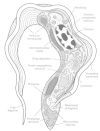
The lack of effective vaccines, the paucity of reliable drugs, and other problems, including difficulties of vector control, prompted the World Health Organization to target six diseases for increased research and training. Three of these were protozoan infections—malaria, trypanosomiasis, and leishmaniasis. Although new information on these diseases has been gained, most of the problems with control persist.

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Structure

Most parasitic protozoa in humans are less than 50 μm in size. The smallest (mainly intracellular forms) are 1 to 10 μm long, but *Balantidium coli* may measure 150 μm. Protozoa are unicellular eukaryotes. As in all eukaryotes, the nucleus is enclosed in a membrane. In protozoa other than ciliates, the nucleus is vesicular, with scattered chromatin giving a diffuse appearance to the nucleus, all nuclei in the individual organism appear alike. One type of vesicular nucleus contains a more or less central body, called an endosome or karyosome. The endosome lacks DNA in the parasitic amebas and trypanosomes. In the phylum Apicomplexa, on the other hand, the vesicular nucleus has one or more nucleoli that contain DNA. The ciliates have both a micronucleus and macronucleus, which appear quite homogeneous in composition.

The organelles of protozoa have functions similar to the organs of higher animals. The plasma membrane enclosing the cytoplasm also covers the projecting locomotory structures such as pseudopodia, cilia, and flagella. The outer surface layer of some protozoa, termed a pellicle, is sufficiently rigid to maintain a distinctive shape, as in the trypanosomes and *Giardia*. However, these organisms can readily twist and bend when moving through their environment. In most protozoa the cytoplasm is differentiated into ectoplasm (the outer, transparent layer) and endoplasm (the inner layer containing organelles); the structure of the cytoplasm is most easily seen in species with projecting pseudopodia, such as the amebas. Some protozoa have a cytosome or cell “mouth” for ingesting fluids or solid particles. Contractile vacuoles for osmoregulation occur in some, such as *Naegleria* and *Balantidium*. Many protozoa have subpellicular microtubules; in the Apicomplexa, which have no external organelles for locomotion, these provide a means for slow movement. The trichomonads and trypanosomes have a distinctive undulating membrane between the body wall and a flagellum. Many other structures occur in parasitic protozoa, including the Golgi apparatus, mitochondria, lysosomes, food vacuoles, conoids in the Apicomplexa, and other specialized structures. Electron microscopy is essential to visualize the details of protozoal structure. From the point of view of functional and physiologic complexity, a protozoan is more like an animal than like a single cell. [Figure 77-1](http://www.ncbi.nlm.nih.gov/books/NBK8325/figure/A4081/?report=objectonly) shows the structure of the bloodstream form of a trypanosome, as determined by electron microscopy.

[](http://www.ncbi.nlm.nih.gov/books/NBK8325/figure/A4081/?report=objectonly)

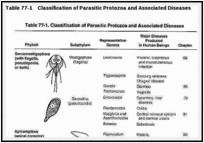
#### [Figure 77-1](http://www.ncbi.nlm.nih.gov/books/NBK8325/figure/A4081/?report=objectonly)

Fine structure of a protozoan parasite, *Typanosoma evansi*, as revealed by transmission electron microcopy of thin sections. (Adapted from Vickerman K: Protozoology. Vol. 3 London School of Hygiene and Tropical Medicine, London, 1977, with permission.) [(more...)](http://www.ncbi.nlm.nih.gov/books/NBK8325/figure/A4081/?report=objectonly)

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Classification

In 1985 the Society of Protozoologists published a taxonomic scheme that distributed the Protozoa into six phyla. Two of these phyla—the Sarcomastigophora and the Apicomplexa--contain the most important species causing human disease. This scheme is based on morphology as revealed by light, electron, and scanning microscopy. *Dientamoeba fragilis*, for example, had been thought to be an ameba and placed in the family Entamoebidae. However, internal structures seen by electron microscopy showed that it is properly placed in the order Trichomonadida of flagellate protozoa. In some instances, organisms that appear identical under the microscope have been assigned different species names on the basis of such criteria as geographic distribution and clinical manifestations; a good example is the genus *Leishmania*, for which subspecies names are often used. Biochemical methods have been employed on strains and species to determine isoenzyme patterns or to identify relevant nucleotide sequences in RNA, DNA, or both. Extensive studies have been made on the kinetoplast, a unique mitochondrion found in the hemoflagellates and other members of the order Kinetoplastida. The DNA associated with this organelle is of great interest. Cloning is widely used in taxonomic studies, for example to study differences in virulence or disease manifestations in isolates of a single species obtained from different hosts or geographic regions. Antibodies (particularly monoclonal antibodies) to known species or to specific antigens from a species are being employed to identify unknown isolates. Eventually, molecular taxonomy may prove to be a more reliable basis than morphology for protozoan taxonomy, but the microscope is still the most practical tool for identifying a protozoan parasite. [Table 77-1](http://www.ncbi.nlm.nih.gov/books/NBK8325/table/A4083/?report=objectonly) lists the medically important protozoa.

[](http://www.ncbi.nlm.nih.gov/books/NBK8325/table/A4083/?report=objectonly)

#### [Table 77-1](http://www.ncbi.nlm.nih.gov/books/NBK8325/table/A4083/?report=objectonly)

Classification of Parasitic Protozoa and Associated Diseases.

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Life Cycle Stages

During its life cycle, a protozoan generally passes through several stages that differ in structure and activity. Trophozoite (Greek for “animal that feeds”) is a general term for the active, feeding, multiplying stage of most protozoa. In parasitic species this is the stage usually associated with pathogenesis. In the hemoflagellates the terms amastigote, promastigote, epimastigote, and trypomastigote designate trophozoite stages that differ in the absence or presence of a flagellum and in the position of the kinetoplast associated with the flagellum. A variety of terms are employed for stages in the Apicomplexa, such as tachyzoite and bradyzoite for *Toxoplasma gondii*. Other stages in the complex asexual and sexual life cycles seen in this phylum are the merozoite (the form resulting from fission of a multinucleate schizont) and sexual stages such as gametocytes and gametes. Some protozoa form cysts that contain one or more infective forms. Multiplication occurs in the cysts of some species so that excystation releases more than one organism. For example, when the trophozoite of *Entamoeba histolytica* first forms a cyst, it has a single nucleus. As the cyst matures nuclear division produces four nuclei and during excystation four uninucleate metacystic amebas appear. Similarly, a freshly encysted *Giardia lamblia* has the same number of internal structures (organelles) as the trophozoite. However, as the cyst matures the organelles double and two trophozoites are formed. Cysts passed in stools have a protective wall, enabling the parasite to survive in the outside environment for a period ranging from days to a year, depending on the species and environmental conditions. Cysts formed in tissues do not usually have a heavy protective wall and rely upon carnivorism for transmission. Oocysts are stages resulting from sexual reproduction in the Apicomplexa. Some apicomplexan oocysts are passed in the feces of the host, but the oocysts of *Plasmodium*, the agent of malaria, develop in the body cavity of the mosquito vector.

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Reproduction

Reproduction in the Protozoa may be asexual, as in the amebas and flagellates that infect humans, or both asexual and sexual, as in the Apicomplexa of medical importance. The most common type of asexual multiplication is binary fission, in which the organelles are duplicated and the protozoan then divides into two complete organisms. Division is longitudinal in the flagellates and transverse in the ciliates; amebas have no apparent anterior-posterior axis. Endodyogeny is a form of asexual division seen in *Toxoplasma* and some related organisms. Two daughter cells form within the parent cell, which then ruptures, releasing the smaller progeny which grow to full size before repeating the process. In schizogony, a common form of asexual division in the Apicomplexa, the nucleus divides a number of times, and then the cytoplasm divides into smaller uninucleate merozoites. In*Plasmodium, Toxoplasma*, and other apicomplexans, the sexual cycle involves the production of gametes (gamogony), fertilization to form the zygote, encystation of the zygote to form an oocyst, and the formation of infective sporozoites (sporogony) within the oocyst.

Some protozoa have complex life cycles requiring two different host species; others require only a single host to complete the life cycle. A single infective protozoan entering a susceptible host has the potential to produce an immense population. However, reproduction is limited by events such as death of the host or by the host's defense mechanisms, which may either eliminate the parasite or balance parasite reproduction to yield a chronic infection. For example, malaria can result when only a few sporozoites of *Plasmodium falciparum*—perhaps ten or fewer in rare instances—are introduced by a feeding*Anopheles* mosquito into a person with no immunity. Repeated cycles of schizogony in the bloodstream can result in the infection of 10 percent or more of the erythrocytes—about 400 million parasites per milliliter of blood.

[Go to:](http://www.ncbi.nlm.nih.gov/books/NBK8325/)

## Nutrition

The nutrition of all protozoa is holozoic; that is, they require organic materials, which may be particulate or in solution. Amebas engulf particulate food or droplets through a sort of temporary mouth, perform digestion and absorption in a food vacuole, and eject the waste substances. Many protozoa have a permanent mouth, the cytosome or micropore, through which ingested food passes to become enclosed in food vacuoles. Pinocytosis is a method of ingesting nutrient materials whereby fluid is drawn through small, temporary openings in the body wall. The ingested material becomes enclosed within a membrane to form a food vacuole.

Protozoa have metabolic pathways similar to those of higher animals and require the same types of organic and inorganic compounds. In recent years, significant advances have been made in devising chemically defined media for the in vitro cultivation of parasitic protozoa. The resulting organisms are free of various substances that are present in organisms grown in complex media or isolated from a host and which can interfere with immunologic or biochemical studies. Research on the metabolism of parasites is of immediate interest because pathways that are essential for the parasite but not the host are potential targets for antiprotozoal compounds that would block that pathway but be safe for humans. Many antiprotozoal drugs were used empirically long before their mechanism of action was known. The sulfa drugs, which block folate synthesis in malaria parasites, are one example.

The rapid multiplication rate of many parasites increases the chances for mutation; hence, changes in virulence, drug susceptibility, and other characteristics may take place. Chloroquine resistance in *Plasmodium falciparum* and arsenic resistance in *Trypanosoma rhodesiense* are two examples.

Competition for nutrients is not usually an important factor in pathogenesis because the amounts utilized by parasitic protozoa are relatively small. Some parasites that inhabit the small intestine can significantly interfere with digestion and absorption and affect the nutritional status of the host; *Giardia* and *Cryptosporidium* are examples. The destruction of the host's cells and tissues as a result of the parasites' metabolic activities increases the host's nutritional needs. This may be a major factor in the outcome of an infection in a malnourished individual. Finally, extracellular or intracellular parasites that destroy cells while feeding can lead to organ dysfunction and serious or life-threatening consequences.

Fungus

A **fungus** ([/ˈfʌŋɡəs/](https://en.wikipedia.org/wiki/Help:IPA_for_English); [plural](https://en.wikipedia.org/wiki/Plural): **fungi**[[3]](https://en.wikipedia.org/wiki/Fungus#cite_note-3) or **funguses**[[4]](https://en.wikipedia.org/wiki/Fungus#cite_note-OxfordDictionary-4)) is any member of the group of [eukaryotic](https://en.wikipedia.org/wiki/Eukaryote) organisms that includes unicellular microorganisms such as [yeasts](https://en.wikipedia.org/wiki/Yeast) and [molds](https://en.wikipedia.org/wiki/Mold), as well as multicellular fungi that produce familiar fruiting forms known as [mushrooms](https://en.wikipedia.org/wiki/Mushrooms). These organisms are classified as a [kingdom](https://en.wikipedia.org/wiki/Kingdom_(biology)), **Fungi**, which is separate from the other eukaryotic life kingdoms of [plants](https://en.wikipedia.org/wiki/Plants) and [animals](https://en.wikipedia.org/wiki/Animals).

A characteristic that places fungi in a different kingdom from plants, bacteria and some protists, is [chitin](https://en.wikipedia.org/wiki/Chitin) in their [cell walls](https://en.wikipedia.org/wiki/Cell_wall). Similar to animals, fungi are [heterotrophs](https://en.wikipedia.org/wiki/Heterotrophs); they acquire their food by absorbing dissolved molecules, typically by secreting [digestive enzymes](https://en.wikipedia.org/wiki/Digestive_enzyme) into their environment. 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*), which share a [common ancestor](https://en.wikipedia.org/wiki/Common_ancestor) (is a [*monophyletic*](https://en.wikipedia.org/wiki/Monophyletic)*group*), an interpretation that is also strongly supported by [molecular phylogenetics](https://en.wikipedia.org/wiki/Molecular_phylogenetics). This fungal group is distinct from the structurally similar[myxomycetes](https://en.wikipedia.org/wiki/Mycetozoa) (slime molds) and [oomycetes](https://en.wikipedia.org/wiki/Oomycetes) (water molds). The discipline of [biology](https://en.wikipedia.org/wiki/Biology) devoted to the study of fungi is known as [mycology](https://en.wikipedia.org/wiki/Mycology) (from the [Greek](https://en.wikipedia.org/wiki/Greek_language) μύκης, mukēs, meaning "fungus"). In the past, mycology was regarded as a branch of [botany](https://en.wikipedia.org/wiki/Botany), although it is now known fungi are genetically more closely related to animals than to plants.

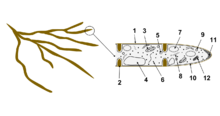
Abundant worldwide, most fungi are inconspicuous because of the small size of their structures, and their [cryptic](https://en.wikipedia.org/wiki/Crypsis)lifestyles in soil or on dead matter. Fungi include [symbionts](https://en.wikipedia.org/wiki/Symbiosis) of plants, animals, or other fungi and also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

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

## Etymology

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

## Characteristics

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

**Fungal hyphae cells**

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

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

Shared features:

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

Unique features:

* Some species grow as unicellular yeasts that reproduce by [budding](https://en.wikipedia.org/wiki/Budding) or [binary fission](https://en.wikipedia.org/wiki/Binary_fission). [Dimorphic fungi](https://en.wikipedia.org/wiki/Dimorphic_fungi) can switch between a yeast phase and a hyphal phase in response to environmental conditions.[[22]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alexopoulos_et_al..2C_p._30-22)
* The fungal cell wall is composed of [glucans](https://en.wikipedia.org/wiki/Glucan) and [chitin](https://en.wikipedia.org/wiki/Chitin); while glucans are also found in plants and chitin in the [exoskeleton](https://en.wikipedia.org/wiki/Exoskeleton) of [arthropods](https://en.wikipedia.org/wiki/Arthropods),[[24]](https://en.wikipedia.org/wiki/Fungus#cite_note-24)[[25]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bowman2006-25) fungi are the only organisms that combine these two structural molecules in their cell wall. Unlike those of plants and oomycetes, fungal cell walls do not contain cellulose.[[26]](https://en.wikipedia.org/wiki/Fungus#cite_note-26)

[](https://en.wikipedia.org/wiki/File:Omphalotus_nidiformis_Binnamittalong_2_email.jpg)

[*Omphalotus nidiformis*](https://en.wikipedia.org/wiki/Omphalotus_nidiformis), a bioluminescent mushroom

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

## Diversity

[](https://en.wikipedia.org/wiki/File:Fungus_in_a_Wood.JPG)

[Bracket fungi](https://en.wikipedia.org/wiki/Bracket_fungus) on a tree stump

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

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

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

Two types of edible fungi

## Mycology

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

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

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

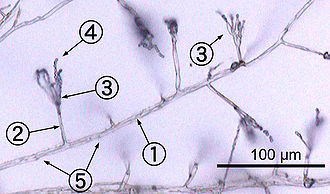
The use of fungi by humans dates back to prehistory; [Ötzi the Iceman](https://en.wikipedia.org/wiki/%C3%96tzi_the_Iceman), a well-preserved mummy of a 5,300-year-old [Neolithic](https://en.wikipedia.org/wiki/Neolithic) man found frozen in the Austrian Alps, carried two species of [polypore](https://en.wikipedia.org/wiki/Polypore)mushrooms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

### History

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

## Morphology

### Microscopic structures

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

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

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

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

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

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

### Macroscopic structures

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

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

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

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

## Growth and physiology

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

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

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

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

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

## Reproduction

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

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

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

### Asexual reproduction

[Asexual reproduction](https://en.wikipedia.org/wiki/Asexual_reproduction) occurs via vegetative spores ([conidia](https://en.wikipedia.org/wiki/Conidium)) or through [mycelial fragmentation](https://en.wikipedia.org/w/index.php?title=Mycelial_fragmentation&action=edit&redlink=1). 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](https://en.wikipedia.org/wiki/Clone_(genetics)) populations adapted to a specific [niche](https://en.wikipedia.org/wiki/Ecological_niche), and allow more rapid dispersal than sexual reproduction.[[77]](https://en.wikipedia.org/wiki/Fungus#cite_note-Heitman2005-77) The "Fungi imperfecti" (fungi lacking the perfect or sexual stage) or [Deuteromycota](https://en.wikipedia.org/wiki/Deuteromycota) comprise all the species that lack an observable sexual cycle.[[78]](https://en.wikipedia.org/wiki/Fungus#cite_note-Alcamo2004-78)

### Sexual reproduction

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

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

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

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

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

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

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

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

### Spore dispersal

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

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

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

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

### Other sexual processes

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

## Evolution

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

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

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

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

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

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

## Taxonomy

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

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

The 2007 classification of Kingdom Fungi is the result of a large-scale collaborative research effort involving dozens of mycologists and other scientists working on fungal taxonomy.[[42]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hibbett2007-42) It recognizes seven [phyla](https://en.wikipedia.org/wiki/Phylum), two of which—the Ascomycota and the Basidiomycota—are contained within a branch representing [subkingdom](https://en.wikipedia.org/wiki/Subkingdom)Dikarya. The accompanying [cladogram](https://en.wikipedia.org/wiki/Cladogram) depicts the major fungal [taxa](https://en.wikipedia.org/wiki/Taxon) and their relationship to opisthokont and unikont organisms, based on the work of Philippe Silar[[125]](https://en.wikipedia.org/wiki/Fungus#cite_note-Silar2016-125) and "The Mycota: A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research".[[126]](https://en.wikipedia.org/wiki/Fungus#cite_note-MycotaVIIS.26E-126) The lengths of the branches are not proportional to [evolutionary](https://en.wikipedia.org/wiki/Evolutionary) distances.

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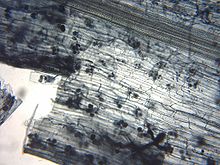
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| [Basidiomycota](https://en.wikipedia.org/wiki/Basidiomycota) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Pucciniomycotina](https://en.wikipedia.org/wiki/Pucciniomycotina) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Tritirachiomycetes](https://en.wikipedia.org/wiki/Tritirachiomycetes) | |  | |  | |  |  | | --- | --- | |  | [Mixiomycetes](https://en.wikipedia.org/wiki/Mixiomycetes) | |  | |  | [Agaricostilbomycetes](https://en.wikipedia.org/wiki/Agaricostilbomycetes) | |  | | |  | | |  | |  | |  |  | | --- | --- | |  | [Cystobasidiomycetes](https://en.wikipedia.org/wiki/Cystobasidiomycetes) | |  | |  | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Classiculaceae](https://en.wikipedia.org/wiki/Classiculaceae) | |  | |  | [Microbotryomycetes](https://en.wikipedia.org/wiki/Microbotryomycetes) | |  | | |  | |  | |  |  | | --- | --- | |  | [Cryptomycocolacomycetes](https://en.wikipedia.org/wiki/Cryptomycocolacomycetes) | |  | |  | |  |  | | --- | --- | |  | [Atractiellomycetes](https://en.wikipedia.org/wiki/Atractiellomycetes) | |  | |  | [Pucciniomycetes](https://en.wikipedia.org/wiki/Pucciniomycetes) | |  | | |  | | |  | | |  | | |  | | |  | | [Orthomycotina](https://en.wikipedia.org/w/index.php?title=Orthomycotina&action=edit&redlink=1) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Ustilaginomycotina](https://en.wikipedia.org/wiki/Ustilaginomycotina) | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Monilielliomycetes](https://en.wikipedia.org/w/index.php?title=Monilielliomycetes&action=edit&redlink=1) | |  | |  | [Malasseziomycetes](https://en.wikipedia.org/w/index.php?title=Malasseziomycetes&action=edit&redlink=1) | |  | | |  | |  | |  |  | | --- | --- | |  | [Ustilaginomycetes](https://en.wikipedia.org/wiki/Ustilaginomycetes) | |  | |  | [Exobasidiomycetes](https://en.wikipedia.org/wiki/Exobasidiomycetes) | |  | | |  | | |  | | [Agaricomycotina](https://en.wikipedia.org/wiki/Agaricomycotina) | |  |  | | --- | --- | |  | [Wallemiomycetes](https://en.wikipedia.org/wiki/Wallemiomycetes) | |  | |  | [Bartheletiomycetes](https://en.wikipedia.org/w/index.php?title=Bartheletiomycetes&action=edit&redlink=1) | |  | |  | |  |  | | --- | --- | |  | [Tremellomycetes](https://en.wikipedia.org/wiki/Tremellomycetes) | |  | |  | |  |  | | --- | --- | |  | [Dacrymycetes](https://en.wikipedia.org/wiki/Dacrymycetes) | |  | |  | [Agaricomycetes](https://en.wikipedia.org/wiki/Agaricomycetes) | |  | | |  | | |  | | |  | | |  | |
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| [Ascomycota](https://en.wikipedia.org/wiki/Ascomycota) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Taphrinomycotina](https://en.wikipedia.org/wiki/Taphrinomycotina) | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Neolectomycetes](https://en.wikipedia.org/wiki/Neolectomycetes) | |  | |  | [Taphrinomycetes](https://en.wikipedia.org/wiki/Taphrinomycetes) | |  | | |  | | [Schizosaccharomyceta](https://en.wikipedia.org/w/index.php?title=Schizosaccharomyceta&action=edit&redlink=1) | |  |  | | --- | --- | |  | [Archaeorhizomycetes](https://en.wikipedia.org/wiki/Archaeorhizomycetes) | |  | |  | |  |  | | --- | --- | |  | [Pneumocystidomycetes](https://en.wikipedia.org/wiki/Pneumocystidomycetes) | |  | |  | [Schizosaccharomycetes](https://en.wikipedia.org/wiki/Schizosaccharomycetes) | |  | | |  | | |  | | |  | | [Saccharomyceta](https://en.wikipedia.org/w/index.php?title=Saccharomyceta&action=edit&redlink=1) | |  |  | | --- | --- | | [Saccharomycotina](https://en.wikipedia.org/wiki/Saccharomycotina) | [Saccharomycetes](https://en.wikipedia.org/wiki/Saccharomycetes) | |  | | [Pezizomycotina](https://en.wikipedia.org/wiki/Pezizomycotina) | |  |  | | --- | --- | |  | ?[Thelocarpales](https://en.wikipedia.org/w/index.php?title=Thelocarpales&action=edit&redlink=1) | |  | |  | ?[Vezdaeales](https://en.wikipedia.org/w/index.php?title=Vezdaeales&action=edit&redlink=1) | |  | |  | ?[Lahmiales](https://en.wikipedia.org/wiki/Lahmiales) | |  | |  | ?[Triblidiales](https://en.wikipedia.org/w/index.php?title=Triblidiales&action=edit&redlink=1) | |  | |  | [Orbiliomycetes](https://en.wikipedia.org/wiki/Orbiliomycetes) | |  | |  | |  |  | | --- | --- | |  | [Pezizomycetes](https://en.wikipedia.org/wiki/Pezizomycetes) | |  | | [Leotiomyceta](https://en.wikipedia.org/wiki/Leotiomyceta) | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | [Sordariomyceta](https://en.wikipedia.org/wiki/Sordariomyceta) | |  |  | | --- | --- | |  | [Xylonomycetes](https://en.wikipedia.org/w/index.php?title=Xylonomycetes&action=edit&redlink=1) | |  | |  | |  |  | | --- | --- | |  | [Geoglossomycetes](https://en.wikipedia.org/wiki/Geoglossomycetes) | |  | |  | |  |  | | --- | --- | |  | [Leotiomycetes](https://en.wikipedia.org/wiki/Leotiomycetes) | |  | |  | |  |  | | --- | --- | |  | [Laboulbeniomycetes](https://en.wikipedia.org/wiki/Laboulbeniomycetes) | |  | |  | [Sordariomycetes](https://en.wikipedia.org/wiki/Sordariomycetes) | |  | | |  | | |  | | |  | | |  | | [Dothideomyceta](https://en.wikipedia.org/wiki/Dothideomyceta) | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Coniocybomycetes](https://en.wikipedia.org/w/index.php?title=Coniocybomycetes&action=edit&redlink=1) | |  | |  | [Lichinomycetes](https://en.wikipedia.org/wiki/Lichinomycetes) | |  | | |  | |  | |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  | |  |  | | --- | --- | |  | [Eurotiomycetes](https://en.wikipedia.org/wiki/Eurotiomycetes) | |  | |  | [Lecanoromycetes](https://en.wikipedia.org/wiki/Lecanoromycetes) | |  | | |  | |  | |  |  | | --- | --- | |  | [Collemopsidiales](https://en.wikipedia.org/w/index.php?title=Collemopsidiales&action=edit&redlink=1) | |  | |  | |  |  | | --- | --- | |  | [Arthoniomycetes](https://en.wikipedia.org/wiki/Arthoniomycetes) | |  | |  | [Dothideomycetes](https://en.wikipedia.org/wiki/Dothideomycetes) | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | | |  | |
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### Taxonomic groups

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

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

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

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

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

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

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

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

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

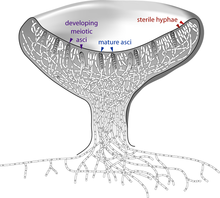
[](https://en.wikipedia.org/wiki/File:Ascocarp2.png)

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

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

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

### Fungus-like organisms

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

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

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

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

The [nucleariids](https://en.wikipedia.org/wiki/Nucleariid), protists currently grouped in the [Choanozoa](https://en.wikipedia.org/wiki/Choanozoa) ([Opisthokonta](https://en.wikipedia.org/wiki/Opisthokonta)), may be the next sister group to the eumycete clade, and as such could be included in an expanded fungal kingdom.[[122]](https://en.wikipedia.org/wiki/Fungus#cite_note-ShalchianTabrizi2008-122)

Many [Actinomycetales](https://en.wikipedia.org/wiki/Actinomycetales) ([Actinobacteria](https://en.wikipedia.org/wiki/Actinobacteria)), a group with many filamentous bacteria, were also long believed to be fungi.

## Ecology

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

A pin mold decomposing a peach

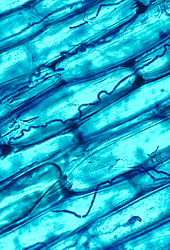
Although often inconspicuous, fungi occur in every environment on [Earth](https://en.wikipedia.org/wiki/Earth) and play very important roles in most [ecosystems](https://en.wikipedia.org/wiki/Ecosystems). Along with bacteria, fungi are the major [decomposers](https://en.wikipedia.org/wiki/Decomposers) in most terrestrial (and some aquatic) ecosystems, and therefore play a critical role in [biogeochemical cycles](https://en.wikipedia.org/wiki/Biogeochemical_cycles)[[140]](https://en.wikipedia.org/wiki/Fungus#cite_note-Gadd2007-140) and in many [food webs](https://en.wikipedia.org/wiki/Food_webs). As decomposers, they play an essential role in [nutrient cycling](https://en.wikipedia.org/wiki/Nutrient_cycling), especially as [saprotrophs](https://en.wikipedia.org/wiki/Saprotroph) and [symbionts](https://en.wikipedia.org/wiki/Symbiont), degrading [organic matter](https://en.wikipedia.org/wiki/Organic_matter) to inorganic molecules, which can then re-enter anabolic metabolic pathways in plants or other organisms.[[141]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lindahl2007-141)[[142]](https://en.wikipedia.org/wiki/Fungus#cite_note-Barea2005-142)

### Symbiosis

Many fungi have important [symbiotic](https://en.wikipedia.org/wiki/Symbiotic) relationships with organisms from most if not all [Kingdoms](https://en.wikipedia.org/wiki/Kingdom_(biology)).[[143]](https://en.wikipedia.org/wiki/Fungus#cite_note-Aanen2006-143)[[144]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nikoh2000-144)[[145]](https://en.wikipedia.org/wiki/Fungus#cite_note-Perotto1997-145) These interactions can be [mutualistic](https://en.wikipedia.org/wiki/Mutualism_(biology)) or antagonistic in nature, or in the case of [commensal](https://en.wikipedia.org/wiki/Commensal) fungi are of no apparent benefit or detriment to the host.[[146]](https://en.wikipedia.org/wiki/Fungus#cite_note-Arnold2003-146)[[147]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paszkowski2006-147)[[148]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hube2004-148)

#### With plants

[Mycorrhizal](https://en.wikipedia.org/wiki/Mycorrhiza) symbiosis between [plants](https://en.wikipedia.org/wiki/Plants) and fungi is one of the most well-known plant–fungus associations and is of significant importance for plant growth and persistence in many ecosystems; over 90% of all plant species engage in mycorrhizal relationships with fungi and are dependent upon this relationship for survival.[[149]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bonfante2003-149)

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

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

The mycorrhizal symbiosis is ancient, dating to at least 400 million years ago.[[131]](https://en.wikipedia.org/wiki/Fungus#cite_note-Remy1994-131) It often increases the plant's uptake of inorganic compounds, such as [nitrate](https://en.wikipedia.org/wiki/Nitrate) and [phosphate](https://en.wikipedia.org/wiki/Phosphate) from soils having low concentrations of these key plant nutrients.[[141]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lindahl2007-141)[[150]](https://en.wikipedia.org/wiki/Fungus#cite_note-Heijden2006-150) The fungal partners may also mediate plant-to-plant transfer of carbohydrates and other nutrients. Such mycorrhizal communities are called "common mycorrhizal networks".[[151]](https://en.wikipedia.org/wiki/Fungus#cite_note-Selosse2006-151) A special case of mycorrhiza is [myco-heterotrophy](https://en.wikipedia.org/wiki/Myco-heterotrophy), whereby the plant parasitizes the fungus, obtaining all of its nutrients from its fungal symbiont.[[152]](https://en.wikipedia.org/wiki/Fungus#cite_note-Merckx2009-152) Some fungal species inhabit the tissues inside roots, stems, and leaves, in which case they are called endophytes.[[153]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schulz2005-153) 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.[[154]](https://en.wikipedia.org/wiki/Fungus#cite_note-Clay2002-154)

#### With algae and cyanobacteria

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

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

[Lichens](https://en.wikipedia.org/wiki/Lichens) are a symbiotic relationship between fungi and [algae](https://en.wikipedia.org/wiki/Algae) or [cyanobacteria](https://en.wikipedia.org/wiki/Cyanobacteria). The algae partner in the relationship is referred to in lichen terminology as a "photobiont". The fungi part of the relationship are composed mostly of various species of [ascomycetes](https://en.wikipedia.org/wiki/Ascomycete) and a few[basidiomycetes](https://en.wikipedia.org/wiki/Basidiomycete).[[155]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brodo2001-155) Lichens occur in every ecosystem on all continents, play a key role in[soil formation](https://en.wikipedia.org/wiki/Soil_formation) and the initiation of [biological succession](https://en.wikipedia.org/wiki/Ecological_succession),[[156]](https://en.wikipedia.org/wiki/Fungus#cite_note-Raven2005-156) and are the dominating life forms in extreme environments, including [polar](https://en.wikipedia.org/wiki/Polar_region), [alpine](https://en.wikipedia.org/wiki/Alpine_climate), and [semiarid](https://en.wikipedia.org/wiki/Semiarid_climate) desert regions.[[157]](https://en.wikipedia.org/wiki/Fungus#cite_note-157) They are able to grow on inhospitable surfaces, including bare soil, rocks, [tree bark](https://en.wikipedia.org/wiki/Bark), wood, shells, barnacles and leaves.[[158]](https://en.wikipedia.org/wiki/Fungus#cite_note-Purvis2000-158) As in [mycorrhizas](https://en.wikipedia.org/wiki/Mycorrhiza), the photobiont provides sugars and other carbohydrates via [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis) to the fungus, while the fungus provides minerals and water to the photobiont. The functions of both symbiotic organisms are so closely intertwined that they function almost as a single organism; in most cases the resulting organism differs greatly from the individual components. Lichenization is a common mode of nutrition for fungi; around 20% of fungi—between 17,500 and 20,000 described species—are lichenized.[[159]](https://en.wikipedia.org/wiki/Fungus#cite_note-159) Characteristics common to most lichens include obtaining [organic carbon](https://en.wikipedia.org/wiki/Organic_carbon) by photosynthesis, slow growth, small size, long life, long-lasting (seasonal) [vegetative reproductive](https://en.wikipedia.org/wiki/Vegetative_reproduction) structures, mineral nutrition obtained largely from airborne sources, and greater tolerance of [desiccation](https://en.wikipedia.org/wiki/Desiccation) than most other photosynthetic organisms in the same habitat.[[160]](https://en.wikipedia.org/wiki/Fungus#cite_note-160)

#### With insects

Many insects also engage in [mutualistic relationships](https://en.wikipedia.org/wiki/Ant-fungus_mutualism) with fungi. Several groups of ants cultivate fungi in the order [Agaricales](https://en.wikipedia.org/wiki/Agaricales) as their primary food source, while[ambrosia beetles](https://en.wikipedia.org/wiki/Ambrosia_beetles) cultivate various species of fungi in the bark of trees that they infest.[[161]](https://en.wikipedia.org/wiki/Fungus#cite_note-Douglas1989-161) Likewise, females of several [wood wasp](https://en.wikipedia.org/wiki/Wood_wasp) species (genus [*Sirex*](https://en.wikipedia.org/wiki/Sirex)) inject their eggs together with spores of the wood-rotting fungus *Amylostereum areolatum* into the [sapwood](https://en.wikipedia.org/wiki/Wood#Heartwood_and_sapwood) of [pine](https://en.wikipedia.org/wiki/Pine) trees; the growth of the fungus provides ideal nutritional conditions for the development of the wasp larvae.[[162]](https://en.wikipedia.org/wiki/Fungus#cite_note-162) At least one species of [stingless bee](https://en.wikipedia.org/wiki/Stingless_bee) has a relationship with a fungus in the genus [*Monascus*](https://en.wikipedia.org/wiki/Monascus), where the larvae consume and depend on fungus transferred from old to new nests.[[163]](https://en.wikipedia.org/wiki/Fungus#cite_note-Sci-News2015-163) [Termites](https://en.wikipedia.org/wiki/Termites) on the African [savannah](https://en.wikipedia.org/wiki/Savannah) are also known to cultivate fungi,[[143]](https://en.wikipedia.org/wiki/Fungus#cite_note-Aanen2006-143) and yeasts of the genera [*Candida*](https://en.wikipedia.org/wiki/Candida_(genus)) and *Lachancea* inhabit the [gut](https://en.wikipedia.org/wiki/Gastrointestinal_tract) of a wide range of insects, including  [neuropterans](https://en.wikipedia.org/wiki/Neuroptera), [beetles](https://en.wikipedia.org/wiki/Beetle), and [cockroaches](https://en.wikipedia.org/wiki/Cockroach); it is not known whether these fungi benefit their hosts.[[164]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nguyen2007-164) The larvae of many families of fungicolous flies, particularly those within the superfamily [Sciaroidea](https://en.wikipedia.org/wiki/Sciaroidea) such as the [Mycetophilidae](https://en.wikipedia.org/wiki/Mycetophilidae) and some[Keroplatidae](https://en.wikipedia.org/wiki/Keroplatidae) feed on fungal fruiting bodies and sterile [mycorrhizae](https://en.wikipedia.org/wiki/Mycorrhizae).[[165]](https://en.wikipedia.org/wiki/Fungus#cite_note-Chandler2010-165)

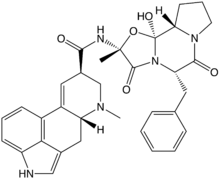
#### As pathogens and parasites

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

Many fungi are [parasites](https://en.wikipedia.org/wiki/Parasite) on plants, animals (including humans), and other fungi. Serious pathogens of many cultivated plants causing extensive damage and losses to agriculture and forestry include the [rice blast](https://en.wikipedia.org/wiki/Rice_blast) fungus [*Magnaporthe oryzae*](https://en.wikipedia.org/wiki/Magnaporthe_oryzae),[[166]](https://en.wikipedia.org/wiki/Fungus#cite_note-Talbot2003-166) tree pathogens such as [*Ophiostoma ulmi*](https://en.wikipedia.org/wiki/Ophiostoma_ulmi) and [*Ophiostoma novo-ulmi*](https://en.wikipedia.org/wiki/Ophiostoma_novo-ulmi) causing [Dutch elm disease](https://en.wikipedia.org/wiki/Dutch_elm_disease),[[167]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paoletti2006-167) and[*Cryphonectria parasitica*](https://en.wikipedia.org/wiki/Cryphonectria_parasitica) responsible for [chestnut blight](https://en.wikipedia.org/wiki/Chestnut_blight),[[168]](https://en.wikipedia.org/wiki/Fungus#cite_note-Gryzenhout2006-168) and plant pathogens in the genera [*Fusarium*](https://en.wikipedia.org/wiki/Fusarium), [*Ustilago*](https://en.wikipedia.org/wiki/Ustilago),[*Alternaria*](https://en.wikipedia.org/wiki/Alternaria), and [*Cochliobolus*](https://en.wikipedia.org/wiki/Cochliobolus).[[147]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paszkowski2006-147) Some [carnivorous fungi](https://en.wikipedia.org/wiki/Carnivorous_fungi), like [*Paecilomyces lilacinus*](https://en.wikipedia.org/wiki/Paecilomyces_lilacinus), are [predators](https://en.wikipedia.org/wiki/Nematophagous_fungus) of [nematodes](https://en.wikipedia.org/wiki/Nematodes), which they capture using an array of specialized structures such as constricting rings or adhesive nets.[[169]](https://en.wikipedia.org/wiki/Fungus#cite_note-Yang2007-169)

Some fungi can cause serious diseases in humans, several of which may be fatal if untreated. These include [aspergillosis](https://en.wikipedia.org/wiki/Aspergillosis),[candidiasis](https://en.wikipedia.org/wiki/Candidiasis), [coccidioidomycosis](https://en.wikipedia.org/wiki/Coccidioidomycosis), [cryptococcosis](https://en.wikipedia.org/wiki/Cryptococcosis), [histoplasmosis](https://en.wikipedia.org/wiki/Histoplasmosis), [mycetomas](https://en.wikipedia.org/wiki/Eumycetoma), and [paracoccidioidomycosis](https://en.wikipedia.org/wiki/Paracoccidioidomycosis). Furthermore, persons with [immuno-deficiencies](https://en.wikipedia.org/wiki/Immunodeficiency) are particularly susceptible to disease by genera such as [*Aspergillus*](https://en.wikipedia.org/wiki/Aspergillus), [*Candida*](https://en.wikipedia.org/wiki/Candida_(genus)),[*Cryptoccocus*](https://en.wikipedia.org/wiki/Cryptococcus_neoformans),[[148]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hube2004-148)[[170]](https://en.wikipedia.org/wiki/Fungus#cite_note-Nielsen2007-170)[[171]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brakhage2005-171) [*Histoplasma*](https://en.wikipedia.org/wiki/Histoplasma),[[172]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kauffman2007-172) and [*Pneumocystis*](https://en.wikipedia.org/wiki/Pneumocystis).[[173]](https://en.wikipedia.org/wiki/Fungus#cite_note-Cushion2007-173) Other fungi can attack eyes, nails, hair, and especially skin, the so-called [dermatophytic](https://en.wikipedia.org/wiki/Dermatophyte) and keratinophilic fungi, and cause local infections such as [ringworm](https://en.wikipedia.org/wiki/Ringworm) and [athlete's foot](https://en.wikipedia.org/wiki/Athlete%27s_foot).[[174]](https://en.wikipedia.org/wiki/Fungus#cite_note-Cook2008-174)Fungal spores are also a cause of [allergies](https://en.wikipedia.org/wiki/Allergies), and fungi from different taxonomic groups can evoke allergic reactions.[[175]](https://en.wikipedia.org/wiki/Fungus#cite_note-SimonNobbe2008-175)

## Mycotoxins

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

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

Many fungi produce [biologically active](https://en.wikipedia.org/wiki/Biological_activity) compounds, several of which are [toxic](https://en.wikipedia.org/wiki/Toxin) to animals or plants and are therefore called[mycotoxins](https://en.wikipedia.org/wiki/Mycotoxins). Of particular relevance to humans are mycotoxins produced by molds causing food spoilage, and poisonous mushrooms (see above). Particularly infamous are the lethal [amatoxins](https://en.wikipedia.org/wiki/Amatoxin) in some [*Amanita*](https://en.wikipedia.org/wiki/Amanita) mushrooms, and [ergot alkaloids](https://en.wikipedia.org/wiki/Ergotamine), which have a long history of causing serious epidemics of [ergotism](https://en.wikipedia.org/wiki/Ergotism) (St Anthony's Fire) in people consuming [rye](https://en.wikipedia.org/wiki/Rye) or related[cereals](https://en.wikipedia.org/wiki/Cereal) contaminated with [sclerotia](https://en.wikipedia.org/wiki/Sclerotia) of the ergot fungus, [*Claviceps purpurea*](https://en.wikipedia.org/wiki/Claviceps_purpurea).[[176]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schardl2007-176) Other notable mycotoxins include the[aflatoxins](https://en.wikipedia.org/wiki/Aflatoxin), which are insidious [liver toxins](https://en.wikipedia.org/wiki/Hepatotoxicity) and highly [carcinogenic](https://en.wikipedia.org/wiki/Carcinogenic) metabolites produced by certain [*Aspergillus*](https://en.wikipedia.org/wiki/Aspergillus) species often growing in or on grains and nuts consumed by humans, [ochratoxins](https://en.wikipedia.org/wiki/Ochratoxin), [patulin](https://en.wikipedia.org/wiki/Patulin), and [trichothecenes](https://en.wikipedia.org/wiki/Trichothecene) (e.g., [T-2 mycotoxin](https://en.wikipedia.org/wiki/T-2_mycotoxin)) and[fumonisins](https://en.wikipedia.org/wiki/Fumonisin), which have significant impact on human food supplies or animal [livestock](https://en.wikipedia.org/wiki/Livestock).[[177]](https://en.wikipedia.org/wiki/Fungus#cite_note-vanEgmond2007-177)

Mycotoxins are secondary metabolites (or [natural products](https://en.wikipedia.org/wiki/Natural_product)), and research has established the existence of biochemical pathways solely for the purpose of producing mycotoxins and other natural products in fungi.[[28]](https://en.wikipedia.org/wiki/Fungus#cite_note-Keller2005-28) Mycotoxins may provide[fitness](https://en.wikipedia.org/wiki/Fitness_(biology)) benefits in terms of physiological adaptation, competition with other microbes and fungi, and protection from consumption ([fungivory](https://en.wikipedia.org/wiki/Fungivore)).[[178]](https://en.wikipedia.org/wiki/Fungus#cite_note-Demain2000-178)[[179]](https://en.wikipedia.org/wiki/Fungus#cite_note-Rohlfs2007-179)

## Pathogenic mechanisms

[*Ustilago maydis*](https://en.wikipedia.org/wiki/Ustilago_maydis) is a pathogenic plant fungus that causes smut disease in maize and [teosinte](https://en.wikipedia.org/wiki/Teosinte). Plants have evolved efficient defense systems against pathogenic microbes such as *U. maydis*. A rapid defense reaction after pathogen attack is the [oxidative burst](https://en.wikipedia.org/wiki/Oxidative_burst) where the plant produces [reactive oxygen species](https://en.wikipedia.org/wiki/Reactive_oxygen_species) at the site of the attempted invasion. *U. maydis* can respond to the oxidative burst with an oxidative stress response, regulated by the gene [*YAP1*](https://en.wikipedia.org/wiki/YAP1). The response protects *U. maydis*from the host defense, and is necessary for the pathogen’s virulence.[[180]](https://en.wikipedia.org/wiki/Fungus#cite_note-Molina2007-180) Furthermore, *U. maydis* has a well-established recombinational [DNA repair](https://en.wikipedia.org/wiki/DNA_repair) system which acts during mitosis and meiosis.[[181]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kojic2006-181) The system may assist the pathogen in surviving DNA damage arising from the host plant’s oxidative defensive response to infection.[[182]](https://en.wikipedia.org/wiki/Fungus#cite_note-Michod2008-182)

[*Cryptococcus neoformans*](https://en.wikipedia.org/wiki/Cryptococcus_neoformans) is an encapsulated yeast that can live in both plants and animals. *C. neoformans* usually infects the lungs, where it is phagocytosed by[alveolar macrophages](https://en.wikipedia.org/wiki/Alveolar_macrophage).[[183]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fan2005-183) Some *C. neoformans* can survive [inside](https://en.wikipedia.org/wiki/Intracellular) macrophages, which appears to be the basis for [latency](https://en.wikipedia.org/wiki/Latency_period), disseminated disease, and resistance to antifungal agents. One mechanism by which *C. neoformans* survives the hostile macrophage environment is by up-regulating the expression of genes involved in the oxidative stress response.[[183]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fan2005-183) Another mechanism involves [meiosis](https://en.wikipedia.org/wiki/Meiosis). The majority of *C. neoformans* are mating "type a". Filaments of mating "type a" ordinarily have haploid nuclei, but they can become diploid (perhaps by endoduplication or by stimulated nuclear fusion) to form [blastospores](https://en.wikipedia.org/wiki/Blastospore). The diploid nuclei of blastospores can undergo meiosis, including recombination, to form haploid basidiospores that can be dispersed.[[184]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lin2005-184) This process is referred to as monokaryotic fruiting. this process requires a gene called [*DMC1*](https://en.wikipedia.org/wiki/DMC1), which is a conserved homologue of genes [*recA*](https://en.wikipedia.org/wiki/RecA) in bacteria and [*RAD51*](https://en.wikipedia.org/wiki/RAD51) in eukaryotes, that mediates homologous chromosome pairing during meiosis and repair of DNA double-strand breaks. Thus, *C. neoformans* can undergo a meiosis, monokaryotic fruiting, that promotes recombinational repair in the oxidative, DNA damaging environment of the host macrophage, and the repair capability may contribute to its virulence.[[182]](https://en.wikipedia.org/wiki/Fungus#cite_note-Michod2008-182)[[184]](https://en.wikipedia.org/wiki/Fungus#cite_note-Lin2005-184)

## Human use

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

[*Saccharomyces cerevisiae*](https://en.wikipedia.org/wiki/Saccharomyces_cerevisiae)cells shown with [DIC microscopy](https://en.wikipedia.org/wiki/Differential_interference_contrast_microscopy)

The human use of fungi for food preparation or preservation and other purposes is extensive and has a long history. [Mushroom farming](https://en.wikipedia.org/wiki/Mushroom_farming) and [mushroom gathering](https://en.wikipedia.org/wiki/Mushroom_gathering) are large industries in many countries. The study of the historical uses and sociological impact of fungi is known as [ethnomycology](https://en.wikipedia.org/wiki/Ethnomycology). Because of the capacity of this group to produce an enormous range of [natural products](https://en.wikipedia.org/wiki/Natural_products) with[antimicrobial](https://en.wikipedia.org/wiki/Antimicrobial) or other biological activities, many species have long been used or are being developed for industrial [production of antibiotics](https://en.wikipedia.org/wiki/Production_of_antibiotics), vitamins, and [anti-cancer](https://en.wikipedia.org/wiki/Taxol#Production) and [cholesterol-lowering](https://en.wikipedia.org/wiki/Lovastatin) drugs. More recently, methods have been developed for [genetic engineering](https://en.wikipedia.org/wiki/Genetic_engineering) of fungi,[[185]](https://en.wikipedia.org/wiki/Fungus#cite_note-Finsham1989-185) enabling [metabolic engineering](https://en.wikipedia.org/wiki/Metabolic_engineering) of fungal species. For example, genetic modification of yeast species[[186]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hawkins2008-186)—which are easy to grow at fast rates in large fermentation vessels—has opened up ways of [pharmaceutical](https://en.wikipedia.org/wiki/Pharmaceutical) production that are potentially more efficient than production by the original source organisms.[[187]](https://en.wikipedia.org/wiki/Fungus#cite_note-Huang2008-187)

### Therapeutic uses

#### Modern chemotherapeutics

Many species produce metabolites that are major sources of [pharmacologically](https://en.wikipedia.org/wiki/Pharmacology) active drugs. Particularly important are the antibiotics, including the [penicillins](https://en.wikipedia.org/wiki/Penicillin), a structurally related group of [β-lactam antibiotics](https://en.wikipedia.org/wiki/%CE%92-lactam_antibiotic) that are synthesized from small [peptides](https://en.wikipedia.org/wiki/Peptide). Although naturally occurring penicillins such as [penicillin G](https://en.wikipedia.org/wiki/Penicillin_G) (produced by [*Penicillium chrysogenum*](https://en.wikipedia.org/wiki/Penicillium_chrysogenum)) have a relatively narrow spectrum of biological activity, a wide range of other penicillins can be produced by [chemical modification](https://en.wikipedia.org/wiki/Chemical_synthesis) of the natural penicillins. Modern penicillins are [semisynthetic](https://en.wikipedia.org/wiki/Semisynthesis) compounds, obtained initially from [fermentation](https://en.wikipedia.org/wiki/Fermentation_(biochemistry)) cultures, but then structurally altered for specific desirable properties.[[188]](https://en.wikipedia.org/wiki/Fungus#cite_note-Brakhage2004-188) Other antibiotics produced by fungi include: [ciclosporin](https://en.wikipedia.org/wiki/Ciclosporin), commonly used as an [immunosuppressant](https://en.wikipedia.org/wiki/Immunosuppressant) during[transplant surgery](https://en.wikipedia.org/wiki/Organ_transplant); and [fusidic acid](https://en.wikipedia.org/wiki/Fusidic_acid), used to help control infection from [methicillin-resistant *Staphylococcus aureus*](https://en.wikipedia.org/wiki/Methicillin-resistant_Staphylococcus_aureus) bacteria.[[189]](https://en.wikipedia.org/wiki/Fungus#cite_note-Pan2008-189) Widespread use of antibiotics for the treatment of bacterial diseases, such as [tuberculosis](https://en.wikipedia.org/wiki/Tuberculosis), [syphilis](https://en.wikipedia.org/wiki/Syphilis), [leprosy](https://en.wikipedia.org/wiki/Leprosy), and others began in the early 20th century and continues to date. In nature, antibiotics of fungal or bacterial origin appear to play a dual role: at high concentrations they act as chemical defense against competition with other microorganisms in species-rich environments, such as the [rhizosphere](https://en.wikipedia.org/wiki/Rhizosphere_(ecology)), and at low concentrations as [quorum-sensing](https://en.wikipedia.org/wiki/Quorum_sensing) molecules for intra- or interspecies signaling.[[190]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fajardo2008-190) Other drugs produced by fungi include [griseofulvin](https://en.wikipedia.org/wiki/Griseofulvin) isolated from [*Penicillium griseofulvum*](https://en.wikipedia.org/wiki/Penicillium_griseofulvum), used to treat fungal infections,[[191]](https://en.wikipedia.org/wiki/Fungus#cite_note-Loo2006-191) and [statins](https://en.wikipedia.org/wiki/Statin) ([HMG-CoA reductase](https://en.wikipedia.org/wiki/HMG-CoA_reductase) inhibitors), used to inhibit[cholesterol synthesis](https://en.wikipedia.org/wiki/Cholesterol_synthesis). Examples of statins found in fungi include [mevastatin](https://en.wikipedia.org/wiki/Mevastatin) from *Penicillium citrinum* and [lovastatin](https://en.wikipedia.org/wiki/Lovastatin) from [*Aspergillus terreus*](https://en.wikipedia.org/wiki/Aspergillus_terreus) and the [oyster mushroom](https://en.wikipedia.org/wiki/Pleurotus_ostreatus).[[192]](https://en.wikipedia.org/wiki/Fungus#cite_note-Manzoni2002-192)

#### Traditional and folk medicine

*See also:*[*Medicinal fungi*](https://en.wikipedia.org/wiki/Medicinal_fungi)

[](https://en.wikipedia.org/wiki/File:Ganoderma_lucidum_01.jpg)

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

The medicinal fungi [*Ganoderma lucidum*](https://en.wikipedia.org/wiki/Ganoderma_lucidum) (left) and [*Ophiocordyceps sinensis*](https://en.wikipedia.org/wiki/Ophiocordyceps_sinensis) (right)

Certain mushrooms enjoy usage as therapeutics in [folk medicines](https://en.wikipedia.org/wiki/Folk_medicine), such as [Traditional Chinese medicine](https://en.wikipedia.org/wiki/Traditional_Chinese_medicine). Notable medicinal mushrooms with a well-documented history of use include [*Agaricus subrufescens*](https://en.wikipedia.org/wiki/Agaricus_subrufescens),[[193]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hetland2008-193)[[194]](https://en.wikipedia.org/wiki/Fungus#cite_note-Firenzuoli2008-194) [*Ganoderma lucidum*](https://en.wikipedia.org/wiki/Ganoderma_lucidum),[[195]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paterson2006-195) and[*Ophiocordyceps sinensis*](https://en.wikipedia.org/wiki/Ophiocordyceps_sinensis).[[196]](https://en.wikipedia.org/wiki/Fungus#cite_note-Paterson2008-196) Research has identified compounds produced by these and other fungi that have inhibitory biological effects against [viruses](https://en.wikipedia.org/wiki/Virus)[[197]](https://en.wikipedia.org/wiki/Fungus#cite_note-elMekkawy1998-197)[[198]](https://en.wikipedia.org/wiki/Fungus#cite_note-ElDine2008-198) and [cancer cells](https://en.wikipedia.org/wiki/Cancer_cells).[[193]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hetland2008-193)[[199]](https://en.wikipedia.org/wiki/Fungus#cite_note-Yuen2005-199) Specific metabolites, such as [polysaccharide-K](https://en.wikipedia.org/wiki/Polysaccharide-K),[ergotamine](https://en.wikipedia.org/wiki/Ergotamine), and [β-lactam antibiotics](https://en.wikipedia.org/wiki/Beta-lactam_antibiotic), are routinely used in clinical medicine. The [shiitake](https://en.wikipedia.org/wiki/Shiitake) mushroom is a source of [lentinan](https://en.wikipedia.org/wiki/Lentinan), a clinical drug approved for use in cancer treatments in several countries, including [Japan](https://en.wikipedia.org/wiki/Japan).[[200]](https://en.wikipedia.org/wiki/Fungus#cite_note-Sullivan2006-200)[[201]](https://en.wikipedia.org/wiki/Fungus#cite_note-Halpern2002-201) In [Europe](https://en.wikipedia.org/wiki/Europe) and [Japan](https://en.wikipedia.org/wiki/Japan),[polysaccharide-K](https://en.wikipedia.org/wiki/Polysaccharide-K) (brand name Krestin), a chemical derived from [*Trametes versicolor*](https://en.wikipedia.org/wiki/Trametes_versicolor), is an approved [adjuvant](https://en.wikipedia.org/wiki/Adjuvant) for cancer therapy.[[202]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fisher2002-202)

### Cultured foods

[Baker's yeast](https://en.wikipedia.org/wiki/Baker%27s_yeast) or [*Saccharomyces cerevisiae*](https://en.wikipedia.org/wiki/Saccharomyces_cerevisiae), a unicellular fungus, is used to make [bread](https://en.wikipedia.org/wiki/Bread) and other wheat-based products, such as [pizza](https://en.wikipedia.org/wiki/Pizza) dough and [dumplings](https://en.wikipedia.org/wiki/Dumpling).[[203]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kulp2000-203)Yeast species of the genus [*Saccharomyces*](https://en.wikipedia.org/wiki/Saccharomyces) are also used to produce [alcoholic beverages](https://en.wikipedia.org/wiki/Alcoholic_beverage) through fermentation.[[204]](https://en.wikipedia.org/wiki/Fungus#cite_note-Piskur2006-204) Shoyu koji mold ([*Aspergillus oryzae*](https://en.wikipedia.org/wiki/Aspergillus_oryzae)) is an essential ingredient in brewing [Shoyu](https://en.wikipedia.org/wiki/Shoyu) ([soy sauce](https://en.wikipedia.org/wiki/Soy_sauce)) and [sake](https://en.wikipedia.org/wiki/Sake), and the preparation of [miso](https://en.wikipedia.org/wiki/Miso),[[205]](https://en.wikipedia.org/wiki/Fungus#cite_note-Abe2006-205) while [*Rhizopus*](https://en.wikipedia.org/wiki/Rhizopus) species are used for making [tempeh](https://en.wikipedia.org/wiki/Tempeh).[[206]](https://en.wikipedia.org/wiki/Fungus#cite_note-Hachmeister1993-206) Several of these fungi are [domesticated](https://en.wikipedia.org/wiki/Domestication) species that were [bred](https://en.wikipedia.org/wiki/Breeding_program) or selected according to their capacity to ferment food without producing harmful mycotoxins (see below), which are produced by very closely related [*Aspergilli*](https://en.wikipedia.org/wiki/Aspergillus_flavus).[[207]](https://en.wikipedia.org/wiki/Fungus#cite_note-Jorgensen2007-207) [Quorn](https://en.wikipedia.org/wiki/Quorn_(food_product)), a [meat substitute](https://en.wikipedia.org/wiki/Meat_analogue), is made from [*Fusarium venenatum*](https://en.wikipedia.org/wiki/Fusarium_venenatum).[[208]](https://en.wikipedia.org/wiki/Fungus#cite_note-ODonnell1998-208)

### Edible and poisonous species

[](https://en.wikipedia.org/wiki/File:Amanita_phalloides_1.JPG)

[*Amanita phalloides*](https://en.wikipedia.org/wiki/Amanita_phalloides) accounts for the majority of fatal [mushroom poisonings](https://en.wikipedia.org/wiki/Mushroom_poisoning)worldwide.

[Edible mushrooms](https://en.wikipedia.org/wiki/Edible_mushroom) are well-known examples of fungi. Many are commercially raised, but others must be harvested from the wild. [*Agaricus bisporus*](https://en.wikipedia.org/wiki/Agaricus_bisporus), sold as button mushrooms when small or Portobello mushrooms when larger, is a commonly eaten species, used in salads, soups, and many other dishes. Many Asian fungi are commercially grown and have increased in popularity in the West. They are often available fresh in [grocery stores](https://en.wikipedia.org/wiki/Grocery_store) and markets, including straw mushrooms ([*Volvariella volvacea*](https://en.wikipedia.org/wiki/Volvariella_volvacea)), oyster mushrooms ([*Pleurotus ostreatus*](https://en.wikipedia.org/wiki/Pleurotus_ostreatus)), shiitakes ([*Lentinula edodes*](https://en.wikipedia.org/wiki/Lentinula_edodes)), and [enokitake](https://en.wikipedia.org/wiki/Enokitake) ([*Flammulina*](https://en.wikipedia.org/wiki/Flammulina) spp.).[[209]](https://en.wikipedia.org/wiki/Fungus#cite_note-Stamets2000-209)

There are many more mushroom species that are [harvested from the wild](https://en.wikipedia.org/wiki/Mushroom_hunting) for personal consumption or commercial sale. [Milk mushrooms](https://en.wikipedia.org/wiki/Lactarius_deliciosus), [morels](https://en.wikipedia.org/wiki/Morel), [chanterelles](https://en.wikipedia.org/wiki/Chanterelle), [truffles](https://en.wikipedia.org/wiki/Truffles), [black trumpets](https://en.wikipedia.org/wiki/Craterellus), and *porcini* mushrooms ([*Boletus edulis*](https://en.wikipedia.org/wiki/Boletus_edulis)) (also known as king boletes) demand a high price on the market. They are often used in gourmet dishes.[[210]](https://en.wikipedia.org/wiki/Fungus#cite_note-210)

Certain types of cheeses require inoculation of milk curds with fungal species that impart a unique flavor and texture to the cheese. Examples include the [blue](https://en.wikipedia.org/wiki/Blue_cheese) color in cheeses such as [Stilton](https://en.wikipedia.org/wiki/Stilton_cheese) or [Roquefort](https://en.wikipedia.org/wiki/Roquefort), which are made by inoculation with[*Penicillium roqueforti*](https://en.wikipedia.org/wiki/Penicillium_roqueforti).[[211]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kinsella1976-211) Molds used in cheese production are non-toxic and are thus safe for human consumption; however, mycotoxins (e.g., aflatoxins, [roquefortine C](https://en.wikipedia.org/wiki/Roquefortine_C), patulin, or others) may accumulate because of growth of other fungi during cheese ripening or storage.[[212]](https://en.wikipedia.org/wiki/Fungus#cite_note-Erdogan2004-212)

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

[Stilton cheese](https://en.wikipedia.org/wiki/Stilton_cheese) veined with[*Penicillium roqueforti*](https://en.wikipedia.org/wiki/Penicillium_roqueforti)

Many mushroom species are [poisonous](https://en.wikipedia.org/wiki/Mushroom_poisoning) to humans, with toxicities ranging from slight digestive problems or [allergic](https://en.wikipedia.org/wiki/Allergy) reactions as well as [hallucinations](https://en.wikipedia.org/wiki/Hallucination) to severe organ failures and death. Genera with mushrooms containing deadly toxins include[*Conocybe*](https://en.wikipedia.org/wiki/Conocybe), [*Galerina*](https://en.wikipedia.org/wiki/Galerina), [*Lepiota*](https://en.wikipedia.org/wiki/Lepiota), and, the most infamous, [*Amanita*](https://en.wikipedia.org/wiki/Amanita).[[213]](https://en.wikipedia.org/wiki/Fungus#cite_note-Orr1979-213) The latter genus includes the destroying angel *(*[*A. virosa*](https://en.wikipedia.org/wiki/Amanita_virosa)*)* and the death cap *(*[*A. phalloides*](https://en.wikipedia.org/wiki/Amanita_phalloides)*)*, the most common cause of deadly mushroom poisoning.[[214]](https://en.wikipedia.org/wiki/Fungus#cite_note-Vetter1998-214) The false morel ([*Gyromitra esculenta*](https://en.wikipedia.org/wiki/Gyromitra_esculenta)) is occasionally considered a delicacy when cooked, yet can be highly toxic when eaten raw.[[215]](https://en.wikipedia.org/wiki/Fungus#cite_note-Leathem2007-215) [*Tricholoma equestre*](https://en.wikipedia.org/wiki/Tricholoma_equestre) was considered edible until it was implicated in serious poisonings causing[rhabdomyolysis](https://en.wikipedia.org/wiki/Rhabdomyolysis).[[216]](https://en.wikipedia.org/wiki/Fungus#cite_note-KarlsonStiber2003-216) [Fly agaric](https://en.wikipedia.org/wiki/Amanita_muscaria) mushrooms (*Amanita muscaria*) also cause occasional non-fatal poisonings, mostly as a result of ingestion for its [hallucinogenic](https://en.wikipedia.org/wiki/Psychedelics,_dissociatives_and_deliriants) properties. Historically, fly agaric was used by different peoples in Europe and Asia and its present usage for religious or [shamanic](https://en.wikipedia.org/wiki/Shamanism) purposes is reported from some ethnic groups such as the [Koryak people](https://en.wikipedia.org/wiki/Koryaks) of north-eastern [Siberia](https://en.wikipedia.org/wiki/Siberia).[[217]](https://en.wikipedia.org/wiki/Fungus#cite_note-Michelot2003-217)

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.[[218]](https://en.wikipedia.org/wiki/Fungus#cite_note-218)[[219]](https://en.wikipedia.org/wiki/Fungus#cite_note-Ammirati1987-219)

### Pest control

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

Grasshoppers killed by [*Beauveria bassiana*](https://en.wikipedia.org/wiki/Beauveria_bassiana)

In agriculture, fungi may be useful if they actively compete for nutrients and space with [pathogenic](https://en.wikipedia.org/wiki/Pathogen) microorganisms such as bacteria or other fungi via the [competitive exclusion principle](https://en.wikipedia.org/wiki/Competitive_exclusion_principle),[[220]](https://en.wikipedia.org/wiki/Fungus#cite_note-LopezGomez2006-220) or if they are [parasites](https://en.wikipedia.org/wiki/Parasitism) of these pathogens. For example, certain species may be used to eliminate or suppress the growth of harmful plant pathogens, such as insects, [mites](https://en.wikipedia.org/wiki/Mites), [weeds](https://en.wikipedia.org/wiki/Weed),[nematodes](https://en.wikipedia.org/wiki/Nematodes), and other fungi that cause diseases of important [crop](https://en.wikipedia.org/wiki/Crop) plants.[[221]](https://en.wikipedia.org/wiki/Fungus#cite_note-urlUSDA_Biocontrol-221) This has generated strong interest in practical applications that use these fungi in the [biological control](https://en.wikipedia.org/wiki/Biological_control) of these agricultural pests. [Entomopathogenic fungi](https://en.wikipedia.org/wiki/Entomopathogenic_fungi) can be used as[biopesticides](https://en.wikipedia.org/wiki/Biopesticides), as they actively kill insects.[[222]](https://en.wikipedia.org/wiki/Fungus#cite_note-urlwww.uvminnovations.com-222) Examples that have been used as [biological insecticides](https://en.wikipedia.org/wiki/Biological_insecticide) are [*Beauveria bassiana*](https://en.wikipedia.org/wiki/Beauveria_bassiana), [*Metarhizium*](https://en.wikipedia.org/wiki/Metarhizium) spp, [*Hirsutella*](https://en.wikipedia.org/wiki/Hirsutella) spp, [*Paecilomyces*](https://en.wikipedia.org/wiki/Paecilomyces) (*Isaria*) spp, and [*Lecanicillium lecanii*](https://en.wikipedia.org/wiki/Lecanicillium_lecanii).[[223]](https://en.wikipedia.org/wiki/Fungus#cite_note-Deshpande1999-223)[[224]](https://en.wikipedia.org/wiki/Fungus#cite_note-Thomas2007-224) [Endophytic](https://en.wikipedia.org/wiki/Endophytic) fungi of grasses of the genus [*Neotyphodium*](https://en.wikipedia.org/wiki/Neotyphodium), such as [*N. coenophialum*](https://en.wikipedia.org/wiki/Neotyphodium_coenophialum), produce alkaloids that are toxic to a range of invertebrate and vertebrate [herbivores](https://en.wikipedia.org/wiki/Herbivores). These alkaloids protect grass plants from [herbivory](https://en.wikipedia.org/wiki/Herbivory), but several endophyte alkaloids can poison grazing animals, such as cattle and sheep.[[225]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bush1997-225) Infecting cultivars of [pasture](https://en.wikipedia.org/wiki/Pasture) or [forage](https://en.wikipedia.org/wiki/Forage) grasses with *Neotyphodium*endophytes is one approach being used in [grass breeding](https://en.wikipedia.org/wiki/Plant_breeding) programs; the fungal strains are selected for producing only alkaloids that increase resistance to herbivores such as insects, while being non-toxic to livestock.[[226]](https://en.wikipedia.org/wiki/Fungus#cite_note-Bouton2002-226)

### Bioremediation

*See also:*[*Mycoremediation*](https://en.wikipedia.org/wiki/Mycoremediation)

Certain fungi, in particular "white rot" fungi, can degrade [insecticides](https://en.wikipedia.org/wiki/Insecticide), [herbicides](https://en.wikipedia.org/wiki/Herbicide), [pentachlorophenol](https://en.wikipedia.org/wiki/Pentachlorophenol), [creosote](https://en.wikipedia.org/wiki/Creosote), [coal tars](https://en.wikipedia.org/wiki/Coal_tar), and heavy fuels and turn them into [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide), water, and basic elements.[[227]](https://en.wikipedia.org/wiki/Fungus#cite_note-Christian2005-227) Fungi have been shown to [biomineralize](https://en.wikipedia.org/wiki/Biomineralization) [uranium](https://en.wikipedia.org/wiki/Uranium) [oxides](https://en.wikipedia.org/wiki/Oxide), suggesting they may have application in the bioremediation of radioactively polluted sites.[[228]](https://en.wikipedia.org/wiki/Fungus#cite_note-BBC2008-228)[[229]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fomina2007-229)[[230]](https://en.wikipedia.org/wiki/Fungus#cite_note-Fomina2008-230)

### Model organisms

Several pivotal discoveries in biology were made by researchers using fungi as [model organisms](https://en.wikipedia.org/wiki/Model_organisms), that is, fungi that grow and sexually reproduce rapidly in the laboratory. For example, the [one gene-one enzyme hypothesis](https://en.wikipedia.org/wiki/One_gene-one_enzyme_hypothesis) was formulated by scientists using the bread mold [*Neurospora crassa*](https://en.wikipedia.org/wiki/Neurospora_crassa) to test their biochemical theories.[[231]](https://en.wikipedia.org/wiki/Fungus#cite_note-Beadle1941-231) Other important model fungi are [*Aspergillus nidulans*](https://en.wikipedia.org/wiki/Aspergillus_nidulans) and the yeasts *Saccaromyces cerevisiae* and [*Schizosaccharomyces pombe*](https://en.wikipedia.org/wiki/Schizosaccharomyces_pombe), each of which with a long history of use to investigate issues in eukaryotic [cell biology](https://en.wikipedia.org/wiki/Cell_biology) and [genetics](https://en.wikipedia.org/wiki/Genetics), such as [cell cycle](https://en.wikipedia.org/wiki/Cell_cycle) regulation, [chromatin](https://en.wikipedia.org/wiki/Chromatin) structure, and [gene regulation](https://en.wikipedia.org/wiki/Gene_regulation). Other fungal models have more recently emerged that address specific biological questions relevant to [medicine](https://en.wikipedia.org/wiki/Medicine), [plant pathology](https://en.wikipedia.org/wiki/Plant_pathology), and industrial uses; examples include [*Candida albicans*](https://en.wikipedia.org/wiki/Candida_albicans), a dimorphic, opportunistic human pathogen,[[232]](https://en.wikipedia.org/wiki/Fungus#cite_note-Datta1989-232) [*Magnaporthe grisea*](https://en.wikipedia.org/wiki/Magnaporthe_grisea), a plant pathogen,[[233]](https://en.wikipedia.org/wiki/Fungus#cite_note-Dean2005-233) and [*Pichia pastoris*](https://en.wikipedia.org/wiki/Pichia_pastoris), a yeast widely used for eukaryotic [protein production](https://en.wikipedia.org/wiki/Protein_production).[[234]](https://en.wikipedia.org/wiki/Fungus#cite_note-Daly2005-234)

### Others

Fungi are used extensively to produce industrial chemicals like [citric](https://en.wikipedia.org/wiki/Citric_acid), [gluconic](https://en.wikipedia.org/wiki/Gluconic_acid), [lactic](https://en.wikipedia.org/wiki/Lactic_acid), and [malic](https://en.wikipedia.org/wiki/Malic_acid) acids,[[235]](https://en.wikipedia.org/wiki/Fungus#cite_note-Schlegel1993-235) and industrial enzymes, such as [lipases](https://en.wikipedia.org/wiki/Lipase) used in [biological detergents](https://en.wikipedia.org/wiki/Biological_detergent),[[236]](https://en.wikipedia.org/wiki/Fungus#cite_note-Joseph2008-236) [cellulases](https://en.wikipedia.org/wiki/Cellulase) used in making [cellulosic ethanol](https://en.wikipedia.org/wiki/Cellulosic_ethanol)[[237]](https://en.wikipedia.org/wiki/Fungus#cite_note-Kumar2008-237) and [stonewashed jeans](https://en.wikipedia.org/wiki/Stonewashed_jeans),[[238]](https://en.wikipedia.org/wiki/Fungus#cite_note-nysaes-238) and [amylases](https://en.wikipedia.org/wiki/Amylase),[[239]](https://en.wikipedia.org/wiki/Fungus#cite_note-OlempskaBeer2006-239) [invertases](https://en.wikipedia.org/wiki/Invertase), [proteases](https://en.wikipedia.org/wiki/Protease) and [xylanases](https://en.wikipedia.org/wiki/Xylanase).[[240]](https://en.wikipedia.org/wiki/Fungus#cite_note-Polizeli2005-240) Several species, most notably [*Psilocybin mushrooms*](https://en.wikipedia.org/wiki/Psilocybin_mushroom) (colloquially known as *magic mushrooms*), are ingested for their [psychedelic](https://en.wikipedia.org/wiki/Psychedelic_drug) properties, both [recreationally](https://en.wikipedia.org/wiki/Recreational_drug) and religiously.