
Welcome to the Museum
ADMIT ALL
Fungarium
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Royal Botanic Gardens Kew

What is a Fungus?

Fungi have a kingdom of their own, like animals and plants do, but theirs is by far the least known. As new species are constantly being discovered, scientists think we have barely scratched the surface and that of the estimated 2.2 to 3.8 million species on Earth, fewer than 5 per cent have been identified.

Historically, fungi were treated as plants and studied by botanists. They were included in *Species Plantarum* by the famous naturalist Linnaeus (also page 48) in 1753. That is why it often comes as a surprise to learn that fungi are more closely related to animals than plants. Just like the outer skeletons of insects and crustaceans, fungal cell walls are made largely of chitin, a substance similar to the keratin of human hair and skin. Plant cell walls contain cellulose instead. Plants manufacture their own food from carbon dioxide in the air, light, and water through a process called photosynthesis. Like animals, fungi can't manufacture their nutrients. Animals ingest their food by engulfing or swallowing it, while fungi secrete enzymes that dissolve food outside their bodies and absorb the nutrients through their cell walls. Another obvious difference is that animals move around to search for food, while fungi grow towards it.

There are at least eight phyla (major groups) of true Fungi, although some researchers recognise up to 18 or more! These phyla include Cryptomycota, Microsporidia, Blastocladiomycota, Chytridiomycota, Zoopagomycota, Mucoromycota, Ascomycota, and Basidiomycota. Some of the most ancient are single-celled and don't look at all like typical fungi. Most familiar fungi belong to Ascomycota and Basidiomycota, which produce septate hyphae (typical fungal filaments) and can include mushrooms, yeasts and those fungi that associate with algae to form lichens.

Key to plate

1: *Razella* sp.
(Cryptomycota)
Motile zoospore
The motile zoospore, with an appendage (flagellum) enabling it to swim, is reminiscent of spermatozoids and reminds us of our close connection to fungi.

2: *Rhizophydium planktonicum*
(Chytridiomycota)
A fungal parasite of microscopic *Asterionella*, this is a freshwater diatom (single-celled algae). These are ancient fungi that mainly live in water and soil.

3: *Piromyces communis*
(Chytridiomycota)
Piromyces communis can be found in the rumen and hindgut of herbivores. These fungi produce enzymes that help the animals digest fibres from plant cell walls. Chytrids are generally single-celled with delicate filaments (rhizoids) penetrating host tissues.

4: *Berwaldia schaefernai*
(Microsporidia)
Spore (sporoblast)
Each spore is surrounded by a vesicle (sac for storage) composed of a thin outer membrane-like sheath and an inner layer of tubular structures (coiled polar tubes). The external layer is made of proteins and chitin. Microsporidians are single-celled parasites of animals.

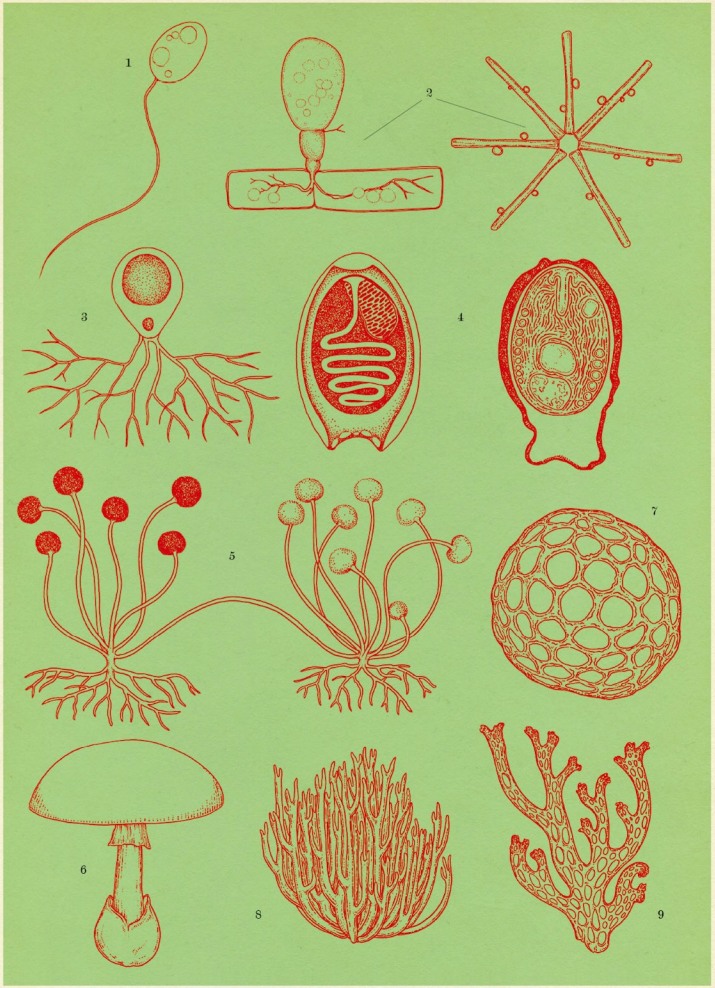
5: Black bread mould
(Mucoromycota)
Rhizopus stolonifer
Mucoromycota have more developed structures than earlier groups, and form networks of filaments, but without the cell-delimiting cross-walls usually found in Ascomycota and Basidiomycota.

6: Caesar's mushroom
(Basidiomycota)
Amanita caesarea
This familiar fungus (also page 54) is found in the phylum Basidiomycota. In basidiomycetes, spores form on microscopic cells known as basidia.

7: Darwin's fungus
(Ascomycota)
Cyttaria darwinii
This belongs to a genus of highly evolved parasitic fungi that only grow on species of southern beech trees. In ascomycete species, spores are formed inside cells known as asci.

8: Upright coral
(Basidiomycota)
Ramaria stricta
This basidiomycete does not look like a typical mushroom. The sporing body has multiple slender and vertical parallel branches covered by spores.

9: *Cladia aggregata* lichen
(Ascomycota)
Around 98 per cent of lichens belong to the phylum Ascomycota. *Cladia* presents a unique growth form with numerous perforations along upright extensions of the thallus (the body of the fungus).



Ecosystem: Mountains

From peak to base, and across snow-covered landscapes, bare stone and luscious forests, mountains provide a diverse range of environments in which many different fungi occur; some of them cannot be found anywhere else in the world. The fungi that live here need to adapt to the severe conditions that become harsher with increasing elevation. Above the treeline, the alpine zone is characterised by short, open vegetation (mostly grasses and small woody plants), low temperatures and high exposure to sun and wind. Here, the ground is covered by snow most of the year. At lower elevations, conditions are less harsh, and trees can grow in deeper and richer soils. The environmental characteristics in each zone shape the communities of fungi and plants that exist there.

At high altitudes, ectomycorrhizal fungi (pages 38–39) are essential for the survival of small alpine woody plants like species of dwarf willows (*Salix*) or mountain avens (*Dryas octopetala*), as well as herbaceous plants like the alpine bistort (*Bistorta vivipara*) and false sedge (*Kobresia*). Fungi here can only fruit during the short period of time after the snow melts and do so much earlier than at lower elevations where the fruiting period is usually longer. The most abundant ectomycorrhizal fungi in alpine habitats above the treeline, include webcaps (*Cortinarius*), fibrecaps (*Inocybe*), poisonpies (*Hebeloma*), deceivers (*Laccaria*), pinkgills (*Entoloma*), milkcaps (*Lactarius*) and brittlegills (*Russula*), which all form gilled mushrooms. Less familiar and detectable, but equally abundant, are crust-like fungi including *Tomentella* and some *Sebacina* species, found under rocks, on soil or decaying wood. Above the treeline lichens can dominate, growing on exposed rock surfaces.

Below the treeline and in the litter layer in the forest (made up of mainly dead plant material on the surface of the soil), other mycorrhizal fungi, such as boletes like *Suillus* and *Leccinum* can be seen, alongside decomposers such as jelly fungi (*Calocera*, staghorns). The stinking parachute (*Gymnopus perforans*), a tiny marasmioid fungus, can also be found in forests.

Key to plate

1: Alpine webcap
Cortinarius alpinus
Seen here forming a symbiotic relationship with the roots of the dwarf willow *Salix herbacea*, the small fruiting bodies of the alpine webcap are taller than their plant host.

2: Alpine brittlegill
Russula nana
This beautiful small mushroom forms a symbiotic relationship with the roots of the alpine bistort, *Bistorta vivipara*, but it can live in symbiosis with other Arctic or alpine plant species.

3: Favre's fibrecap
Inocybe favrei
This mushroom forms a symbiotic relationship with the roots of mountain avens (*Dryas octopetala*), seen here. It is named after the pioneering Swiss geologist Jules Favre.

4: Gassy webcap
Cortinarius traganus
The violet fruiting body of this fungus is well known for its strong, unpleasant scent. It forms symbiotic relationships with roots of pine and birch trees.

5: Yellow stagshorn
Calocera viscosa
This fiery bright fungus grows in dead wood. The name '*calocera*' means 'beautiful and waxy', while '*viscosa*' means sticky. This is fitting, as it can be used as a chewing gum.

6: Stinking parachute
Gymnopus perforans
These miniature fungi form sporing bodies around fallen conifer needles. Despite their small size, they smell strongly of rotten cabbage.

7: Weeping bolete
Suillus granulatus
With a greasy cap and dots on the stipe (stem), this mushroom forms a symbiotic relationship with the roots of pine trees. When young, it releases milky droplets that give it its name.

8: Orange birch bolete
Leccinum versipelle
This large bolete forms a symbiotic relationship only with birch trees.

Mycorrhizal Networks

Mycorrhizal fungi are connected to the roots of their host plants forming mycorrhizas. These extend into the soil through their fungal filaments. One fungus can be attached to the roots of many plants (of the same or different species) and one plant can be attached to many different fungi. A tree can harbour dozens of fungi in its roots. In this way, plants can be connected to each other below ground through their roots by these fungi, forming the 'wood wide web'.

The interconnected filaments that the fungi form can be as vast and complex as forests. Sometimes we see evidence of them above ground in the form of mushrooms or crusts, and below ground in the form of truffles. These are just the tip of the iceberg; the sporing bodies of the huge below-ground functional part of these fungi. These form extraordinarily complex communication systems known as mycorrhizal networks. In fact, a gram of soil can contain hundreds and hundreds of these fungal filaments.

Each fine root of an oak tree, as in many other trees in temperate and boreal ecosystems, is fully sheathed by a fungus which forms an ectomycorrhiza (page 36) structure formed by fungus and root). These allow the mycorrhizal network to take shape. From the ectomycorrhizas, fungal filaments extend deep into the soil, gathering nutrients and water. These are transferred to trees in exchange for plant carbohydrates that the fungi use for their own growth and to form sporing bodies.

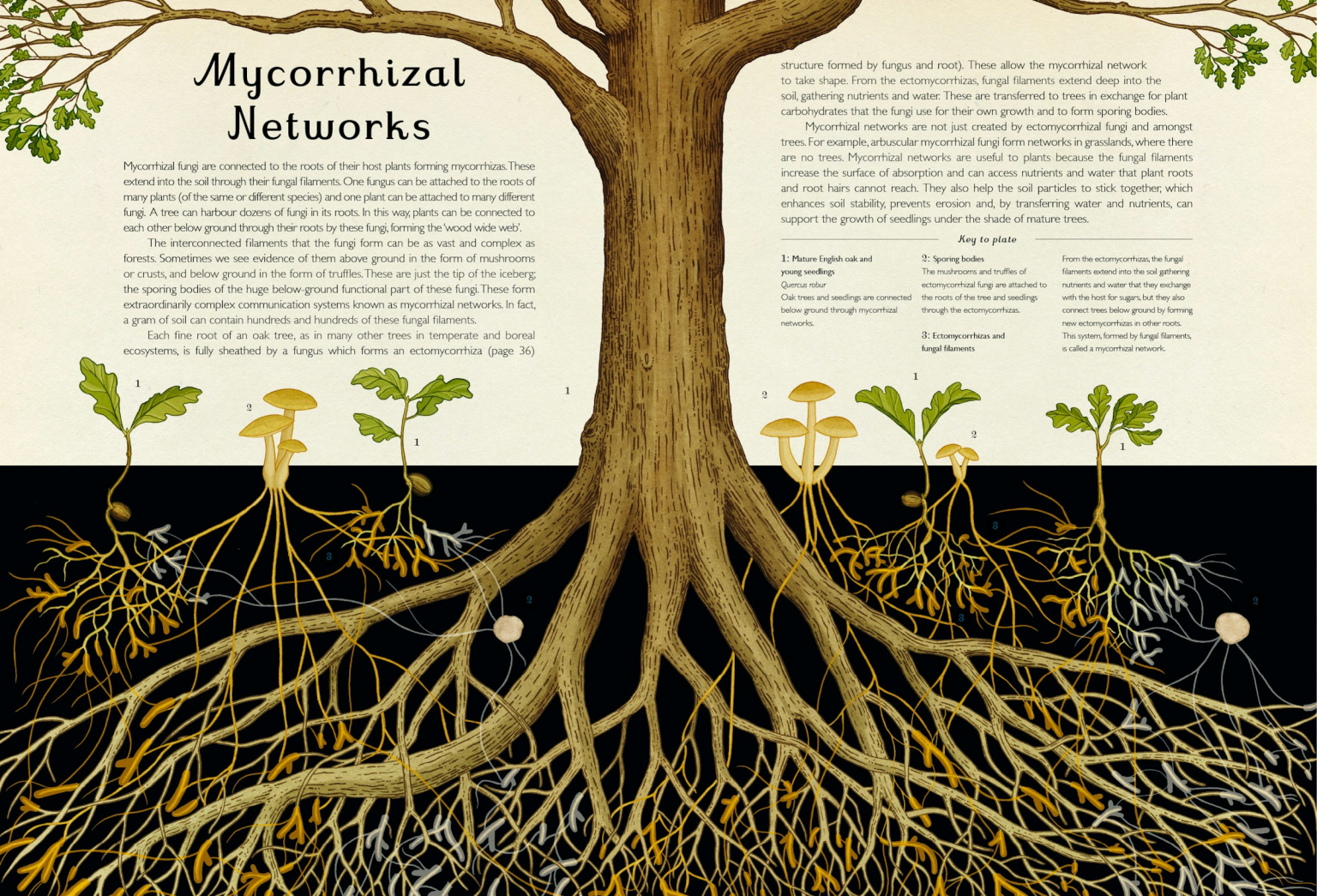
Mycorrhizal networks are not just created by ectomycorrhizal fungi and amongst trees. For example, arbuscular mycorrhizal fungi form networks in grasslands, where there are no trees. Mycorrhizal networks are useful to plants because the fungal filaments increase the surface of absorption and can access nutrients and water that plant roots and root hairs cannot reach. They also help the soil particles to stick together, which enhances soil stability, prevents erosion and, by transferring water and nutrients, can support the growth of seedlings under the shade of mature trees.

Key to plate

1: Mature English oak and young seedlings
Quercus robur
Oak trees and seedlings are connected below ground through mycorrhizal networks.

2: Sporing bodies
The mushrooms and truffles of ectomycorrhizal fungi are attached to the roots of the tree and seedlings through the ectomycorrhizas.

3: Ectomycorrhizas and fungal filaments
From the ectomycorrhizas, the fungal filaments extend into the soil gathering nutrients and water that they exchange with the host for sugars, but they also connect trees below ground by forming new ectomycorrhizas in other roots. This system, formed by fungal filaments, is called a mycorrhizal network.



Plant Pathogens

Although most fungi perform helpful roles in recycling nutrients in ecosystems, some have adopted a different lifestyle that is harmful to the plants they interact with. Fungi that attack plants (fungal plant pathogens), are a major cause of crop damage, causing huge financial costs in agriculture and even threatening the supply of food to our tables. The price we pay for common food items in the shops is dependent on our success in our ongoing struggle with these fungi. It is estimated that 8–21 per cent of the six major food crops are lost to fungal pathogens and a further 10 per cent is lost after the crops are harvested.

New plant pathogens emerge on a regular basis, but our knowledge of their existence extends back to antiquity. A student of Aristotle, Theophrastus, provided one of the first written descriptions of fungal rust diseases. In the seventeenth century in Europe, farmers observed a connection between the presence of barberry plants growing on the margins of wheat fields and the levels of stem rust damage to wheat. This proved to be a valuable insight as barberry is now known to act as a host for the wheat stem rust *Puccinia graminis*. Digging up and destroying the barberry plants turned out to be an effective way of controlling the rust disease.

Fungi adopt three broad strategies to infecting plants. They can infect plants and live off their nutrients while keeping the plants alive (biotrophs), they can kill plants outright and digest the dead plant matter (necrotrophs) or they can start out as biotrophs but then switch to a necrotrophic lifestyle later. Infection begins when a fungal spore lands on a plant. Next, hyphae (page 16) emerge from the spore and spread across the surface of the leaf looking for a way in. Some fungi such as the rusts search out a natural opening – the stomatal pores which allow water in and out of a plant's leaves, for example. Others use a hardened hyphal tip to push through the leaf surface. Once they have gained entry, fungal pathogens interfere with the plant's ability to defend itself. For example, necrotrophic pathogens may release toxins to kill plant cells and then digest them. Biotrophic fungal pathogens keep infected tissue alive against the will of the plant which is trying to stop the infection.

Key to plate

1: Basal stem rot
Ganoderma orbiforme
This fungus causes basal stem rot in oil palm plantations in Southeast Asia. The fungus produces woody brackets on the side of the infected tree.

2: Dutch elm disease
Ophiostoma novo-ulmi
This is a particularly aggressive cause of Dutch elm disease. It is spread by a bark beetle that lives in galleries inside the bark of the trees.

3: Witches' broom disease
Moniliophthora perniciosa
This pathogen infects cocoa trees, causing reduction in yield of up to 90 per cent. It is also resistant to fungicides.

4: Rice blast disease
Pyricularia oryzae
This infects rice plants, causing brownish lesions to appear on the leaves. It destroys enough rice a year to feed 60 million people.

5: Dark honey fungus
Armillaria ostoyae
Some honey fungi are major pathogens of trees and shrubs, forming black strands (rhizomorphs) which spread through the soil and split the bark from the wood. One colony of *Armillaria gallica* forms the 'humongous fungus' occupying 70 hectares of forest in Michigan State (United States). It is believed to be the largest organism on Earth.