

SYSTEMATICS OF FUNGI

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Summary

Taxonomic boundaries, subdivision and examples of relevant species for each main systematic group in the kingdom Fungi or Eumycota are reported. Four phyla of organisms typically adapted to terrestrial habitats, possessing a chitinous cell wall, feeding by absorption on organic carbon compounds, are described and illustrated. Fungi typically lack motile cells; only Chytridiomycota possess flagellate cells (zoospores) in a phase of their life cycle; they include agents of serious plant diseases of potatoes tubers, *Synchytrium endobioticum*, and of cabbage, *Pleotrachelus brassicae*.

Zygomycota are filamentous, coenocytic, i.e., with multinucleate hyphae lacking septa, and without flagella; they produce zygospores, i.e., thick-walled, diploid sexual resting spores, within zygosporangia, and produce asexual haploid sporangiospores within sporangia. The class Zygomycetes includes the very common saprobic 'sugar fungi' in

the Mucorales, symbionts of higher plants in the Glomales, which form arbuscular endomycorrhizae (AM), and Endogonales, which form ectomycorrhizae. Insect parasites are included in the Entomophthorales, and obligate fungicolous parasites or predators in the Zoopagales. The class Trichomycetes includes endosymbionts, living in the gut of insects and other arthropods.

Ascomycota, characterized by the presence of the ascus (a sac-like cell, which produces ascospores), can be either single-celled (yeasts), or filamentous with septate hyphae, or both (dimorphic). The class Archiascomycetes includes fungi with yeast-like growth (at least in culture), lacking ascomata, as *Taphrina deformans*, the agent of peach leaf curl disease. The class Saccharomycetes includes yeasts, such as *Saccharomyces cerevisiae*, the yeast used in baking, brewing and wine production. Ascomycetes are filamentous fungi with septate mycelium, characterized by fruiting bodies or ascomata having different shapes and organizations. They include pathogens of man, such as *Arthroderma spp.* (which cause dermatophytoses, such as tinea and ring worm disease of the skin), pathogens of plants, such as *Ophiostoma ulmi* and *O. novo-ulmi* (causing Dutch elm disease), and ectomycorrhizal symbionts of plant roots, such as *Tuber spp.* (truffles).

Conidial or mitosporic fungi consist of fungi producing spores mitotically, for which, in some cases, a connection with a sexual state has been established, mostly with ascomycetes, more rarely with basidiomycetes, but most of them have not been correlated with any meiotic state.

Basidiomycota include the plant pathogen rusts, smuts, and bunt fungi as well as the fungi popularly called mushrooms, toadstools, puffballs, shelf fungi, stinkhorns, bird's nest fungi, and jelly fungi. Many of these are saprobes, some are ectomycorrhizal symbionts of plant roots, while others are parasites. *Puccinia graminis*, the agent of black stem rust, is representative of Urediniomycetes, and *Ustilago maydis*, which causes the common corn smut, of Ustilaginomycetes. The class Hymenomycetes includes aphyllophoralean orders, fruiting bodies which are known as shelf and bracket fungi, pore fungi, tooth fungi, coral fungi, and club fungi; it also includes agaricoid orders, many of which are ectomycorrhizal fungi with fleshy and stalked fruiting bodies, as in the genera *Russula*, *Lactarius*, and *Amanita*. *Amanita virosa* is the poisonous 'destroying angel', *A. phalloides* is commonly called death cup, and *A. caesarea* is the edible 'Caesar's mushroom'; in the gasteromycetous orders puffballs, earthstars, bird nest's fungi, and stinkhorns, as *Phallus impudicus*, are included.

1. Introduction

In 1969, Whittaker proposed the five kingdom system, where the Fungi represented a branch separate from those of plants, animals, monera and protista (see *Biological Sciences Fundamentals*). Since that time, however, the boundaries of the kingdom Fungi have undergone changes. Ultra-structural, biochemical, as well as molecular evidence suggests that four phyla, Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota, are properly included in it. On the other hand, organisms such as myxomycetes, hyphochytridiomycetes, and oomycetes, formerly included in the Kingdom Fungi, nowadays belong to the Kingdom Protoctista. Recent proposals

recommend the creation of the kingdoms Protozoa, including myxomycetes, and Chromista which includes hypochytridiomycetes and oomycetes.

2. Kingdom Fungi

The kingdom Fungi, or Eumycota, is composed of four phyla, to which about 56 000 known species belong. The estimated number of extant fungal species, however, lies between 1 and 1.5 millions, thus suggesting that the bulk of biodiversity in this kingdom has yet to be described. A possible phylogenetic tree of fungi is reported in Figure 1.

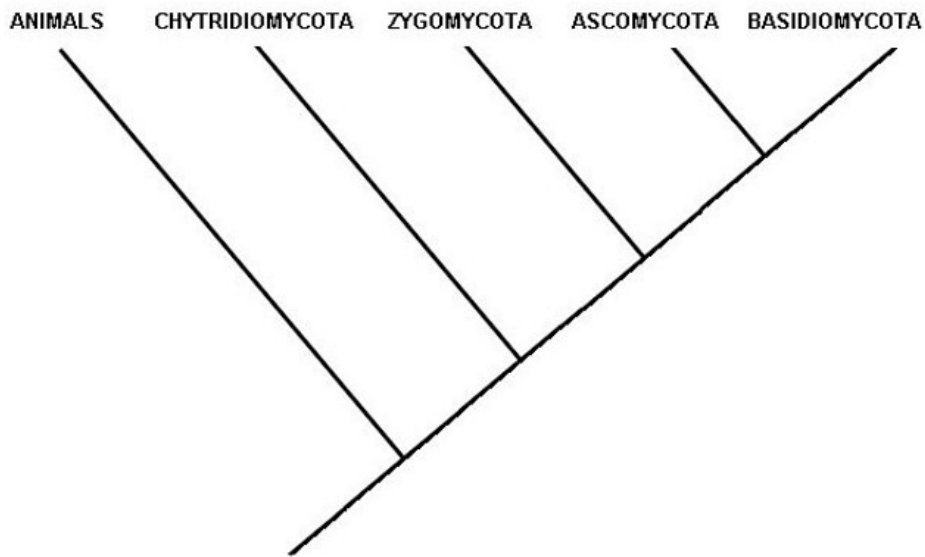


Figure 1. Phylogenetic relationships among fungi and with the animal kingdom.

Fungi are typically filamentous organisms; single filaments are termed hyphae (singular hypha) and possess a cell wall generally composed of chitin (polymer of N-acetylglucosamine) and glucans (branched polymers of glucose) as the main components. Hyphae grow apically, and branch periodically behind the tips forming a hyphal network termed mycelium. Yeasts are unicellular fungi that lost the mycelial habit during their evolution.

Fungi are typically adapted to terrestrial habitats, possessing a chitinous cell wall and typically lacking motile cells; only Chytridiomycota possess flagellate cells (zoospores) in a phase of their life cycle.

Fungal nutrition is heterotrophic, i.e., depending on organic carbon compounds, by absorption. Fungi can degrade practically any kind of substances, including extremely tough compounds such as cellulose, lignin, keratin, and chitin, which are the main part of the organic substrates present in nature. Extra-cellular enzymes are secreted to obtain simple, soluble nutrients to be absorbed. Fungi may live as saprobes on organic matter, as parasites on plants, animals, including man, and practically any kind of organisms, or as symbionts, forming lichens with algae and/or cyanobacteria. When symbiotic, fungi also grow as endophytes in plant leaf and stem tissues and form mycorrhizae with higher plants roots.

2.1. Phylum Chytridiomycota

Chytridiomycota are the oldest and most primitive fungi whose known fossils date from the Lower Devonian, about 400 millions years before present (MYBP). This phylum contains only a single class (Chytridiomycetes) separated in to five orders (Chytridiales, Spizellomycetales, Blastocladales, Monoblepharidales, and Neocallimastigales). In the chytrids, there are approximately 100 genera and about 800 species of coenocytic (multinucleate) organisms. The presence of a chitinous cell wall, nutrition by absorption, and data based on DNA sequences led to the inclusion of chytrids in the kingdom Fungi, in spite of the presence of unflagellate spores formed in globose to ellipsoid sporangia. The complexity of the thallus varies from a sporangium with root-like structures (rhizoids) to mycelial forms lacking regular septation. In holocarpic species the whole thallus is converted into reproductive structures, while in eucarpic species reproductive organs derive from only a portion of the thallus. Chytrids are present in both water and soil, even in desert soils. They live as saprobes on different substrates, namely cellulose, chitin, and keratin, or as parasites on plants, phytoplankton, fungi and animals such as rotifers, tardigrades, nematodes, dipterans, and coleopterans. *Batrachochytrium dendrobatidis* is a dangerous pathogen of frogs. Few anaerobic species grow in the gut of ruminants.

The approximately 500 species belonging to the order Chytridiales mainly occur in fresh water habitats, but also in marine environments and in soil. In the family Chytridiaceae, the genera *Chytridium*, *Chytriomycetes*, and *Rhizophyidium* are common. Some of them are parasitic on other fungi, algae and higher plants. *Synchytrium endobioticum* (fam. Synchytriaceae) causes a serious disease of potato tubers, called black wart disease.

The Spizellomycetales mainly differ from Chytridiales in zoospore ultra-structure. They mostly occur in soil, seldom in water. Both saprobic and parasitic species are present within this order. *Pleotrachelus brassicae* (widely known under the synonym *Olpidium brassicae*) parasitizes cabbage roots to which it transmits number of plant viruses, it also infects lettuce seedlings and other plants. Thick-walled, resistant sporangia characterize the species in the Blastocladales. *Catenaria* and *Coelomomyces* are parasitic on animals and *Physoderma* on plants. *Allomyces macrogynus* is commonly used as experimental organism in cellular and molecular biology.

Most species of Monoblepharidales are saprobic on fruits and twigs submerged in fresh water. Species in the small order Neocallimastigales are obligatory anaerobic organisms living in the rumen and caecum of herbivores, where they contribute to cellulose digestion; representative genera are *Neocallimastix*, *Pyromyces*, and *Orpinomyces*.

2.2. Phylum Zygomycota

Members of the Phylum Zygomycota - including about 170 genera and more than 1 000 species - produce zygospores, i.e., thick-walled, diploid sexual resting spores, within zygosporangia, formed by the fusion of two gametangia, produced from the same (homothallic) or different mycelia (heterothallic). Asexual haploid sporangiospores are produced within sporangia; some species produce chlamydospores (i.e., resistant thick-

walled mitospore, intercalary or terminal, formed by modification of a single hyphal segment). They are filamentous, coenocytic, i.e., with multinucleate hyphae lacking septa, and without flagella.

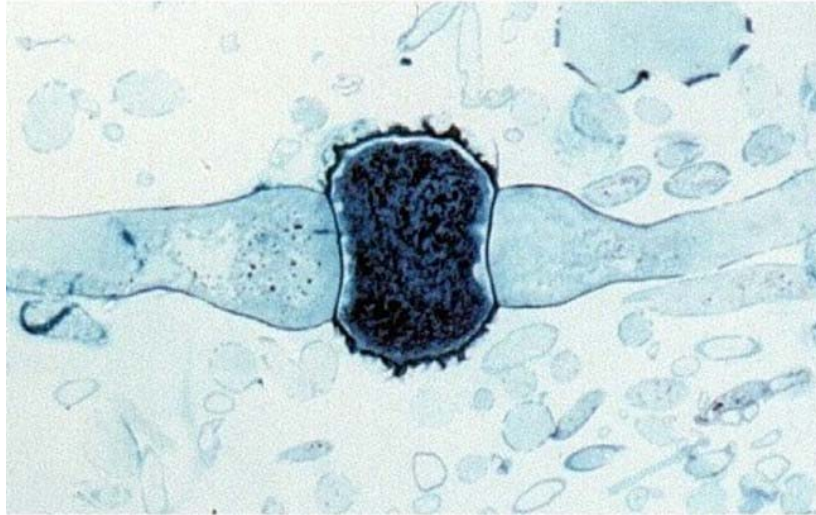


Figure 2. Zygosporangium of *Rhizopus* (Mucorales, Zygomycota), which contains a single zygospore, diploid sexual spore, formed by fusion of gametangia.



Figure 3. Sporangium of *Rhizopus* (Mucorales, Zygomycota), which contains sporangiospores, haploid asexual spores, surrounding the enlarged columella at the tip of a long stalk.

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Biographical Sketches

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