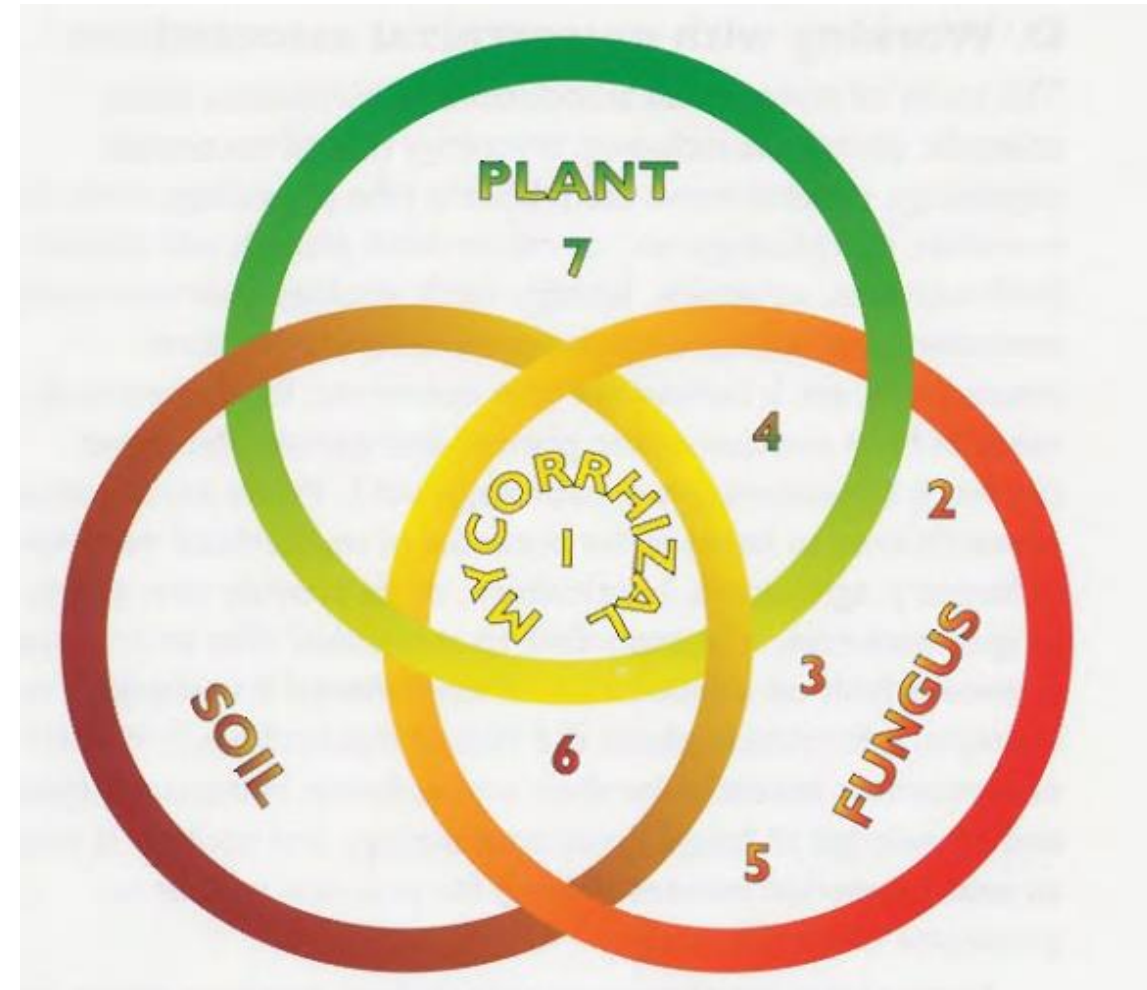
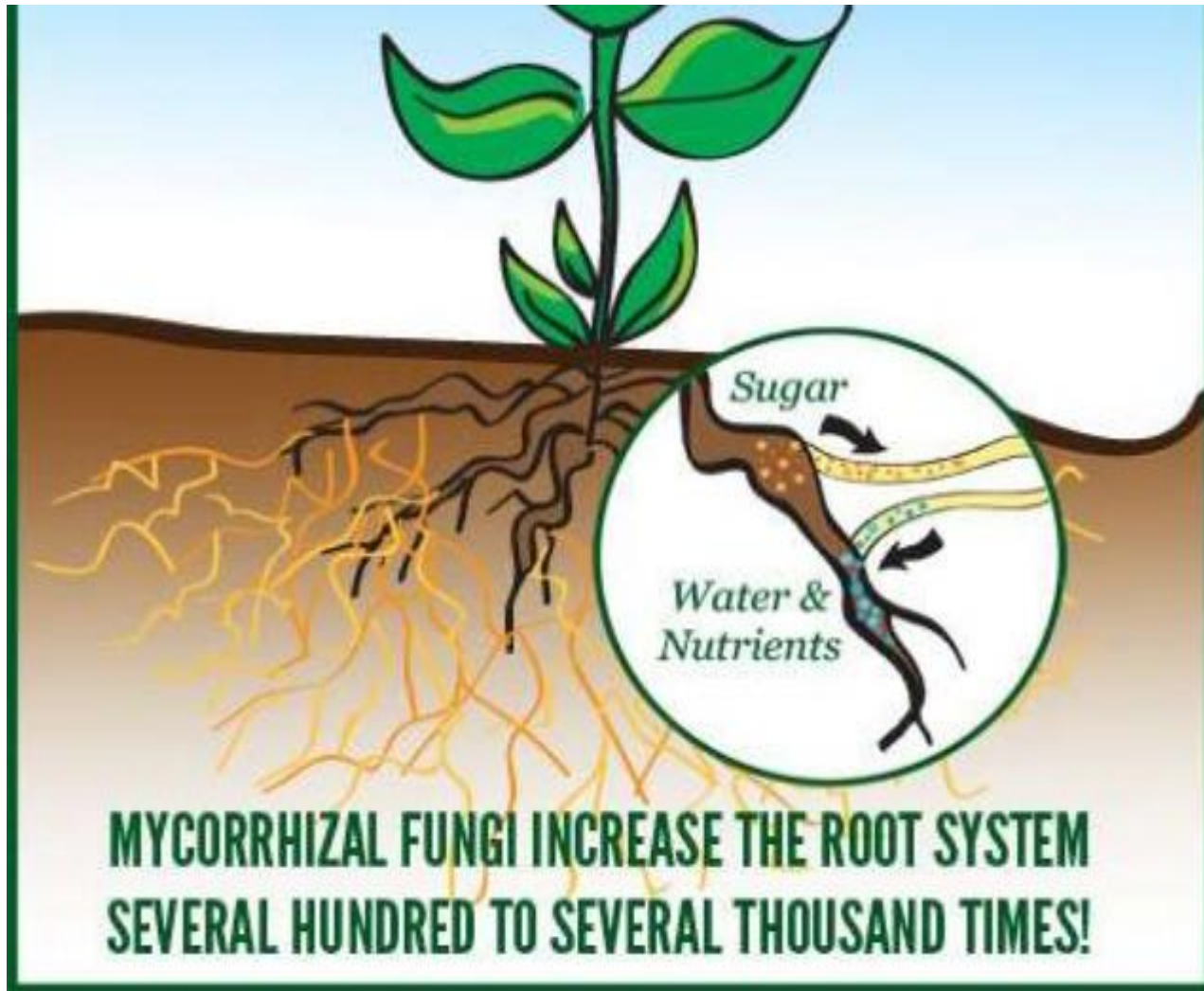


MYCORRHIZAL ASSOCIATIONS



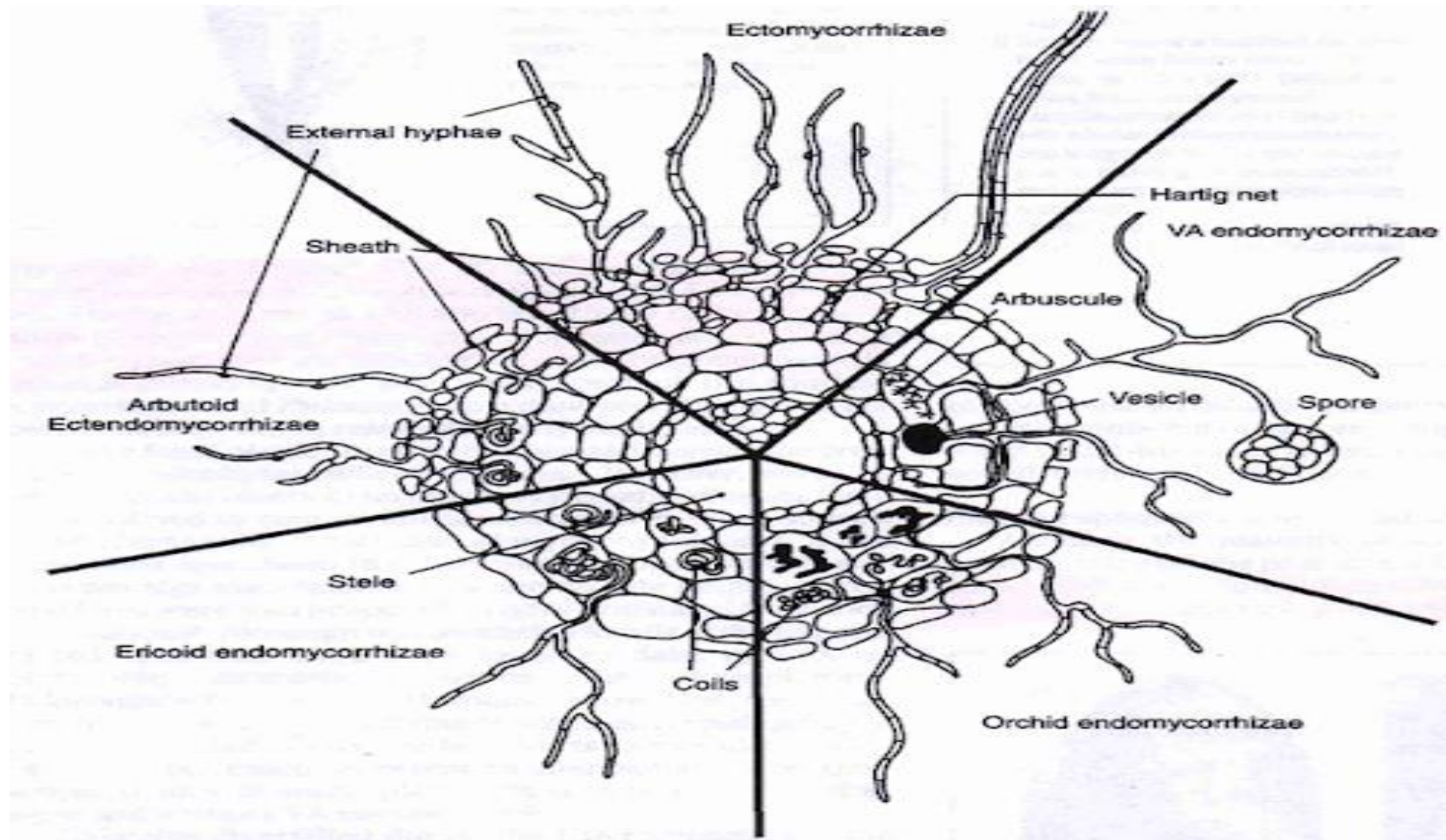
Introduction :

- *Mycorrhizae* are mutualistic symbiotic associations formed between the roots of higher plants and fungi.
- It is an Greek word, mykes: mushroom or fungi; rhiza: root.
- Fungal roots were discovered by the German botanist A B Frank in the last century (1855) in forest trees such as pine.
- In nature approximately 90% of plants are infected with mycorrhizae. 83% Dicots, 79% Monocots and 100% Gymnosperms.
- Convert insoluble form of phosphorous in soil into soluble form.

Types of mycorrhizae :

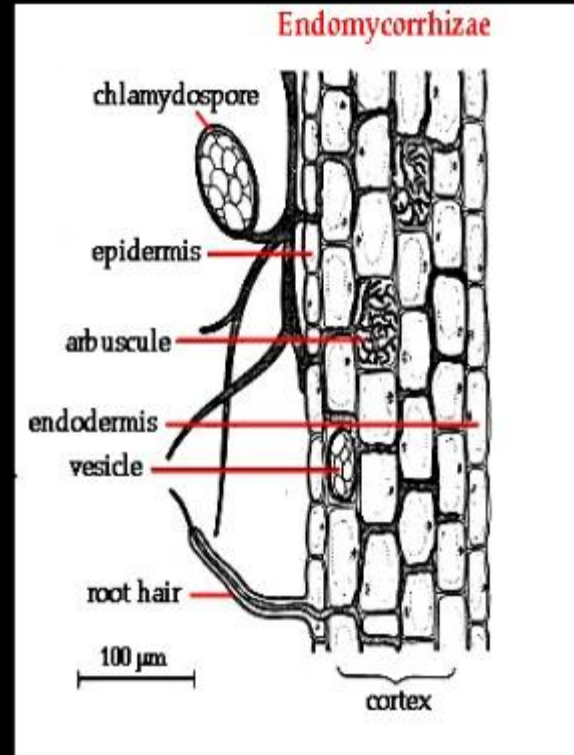
- On the basis of morphological and anatomical features, mycorrhizae are divided into the three types.
 1. Endomycorrhizae
 2. Ectomycorrhizae
 3. Ectendomycorrhizae

- Endomycorrhizae further classified in to five types.
 1. VAM fungi (vesicular arbuscular mycorrhizae)
 2. Orchidoid mycorrhizae
 3. Monotropoid mycorrhizae
 4. Ericoid Mycorrhizae
 5. Arbutoid mycorrhizae



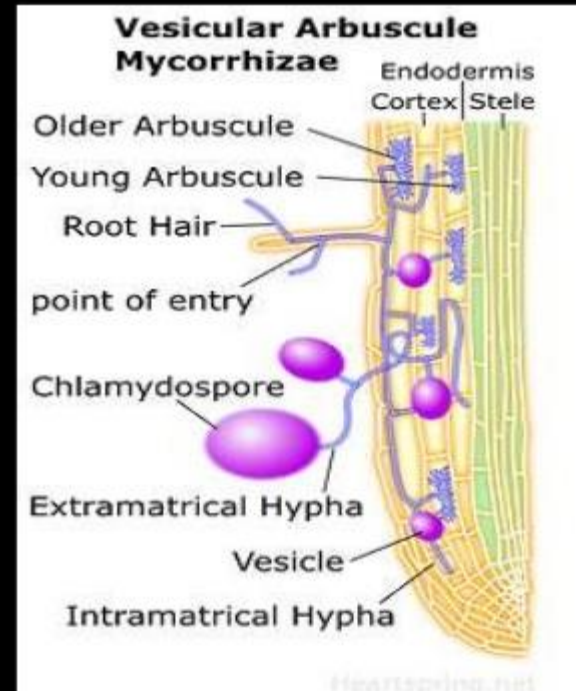
Endomycorrhizae :

- It is a mycorrhizal association in which the fungal hyphae are present on root surface as individual threads that may penetrate directly into root hairs, other epidermal cells & into cortical cells.



VAM fungi (Vesicular Arbuscule mycorrhizae) :

- Fungi formed VAM association with plants may belongs to ascomycetes, basidiomycetes and zygomycetes.
- All VAM fungi are obligate biotrophic, as they are completely dependent on plants for their survival.

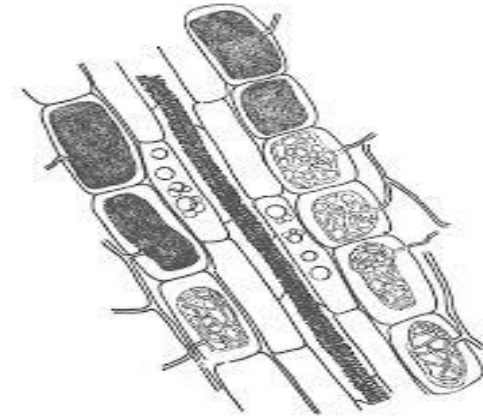
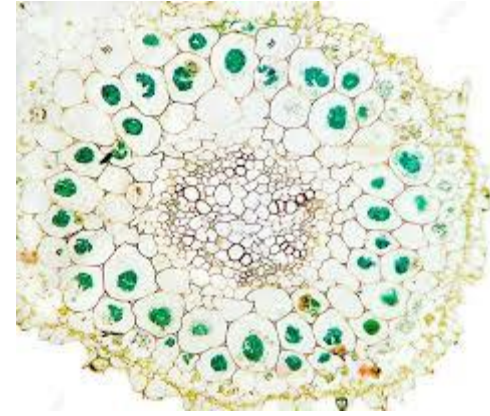


Orchidoid Mycorrhizae :

- Fungi belongs to basidiomycotina and colonize only member of family orchidaceae. This association is probably pseudomycorrhizal but play an important role in establishment of orchid seedlings.

Ericoid Mycorrhizae :

- Fungal members are usually basidiomycetous and Ascomycotina. This is found in roots of plants belonging to order ericales. Rootlets are covered by a loosely woven mesh of dark brown septate hyphae from which branches penetrate the cortical cells.

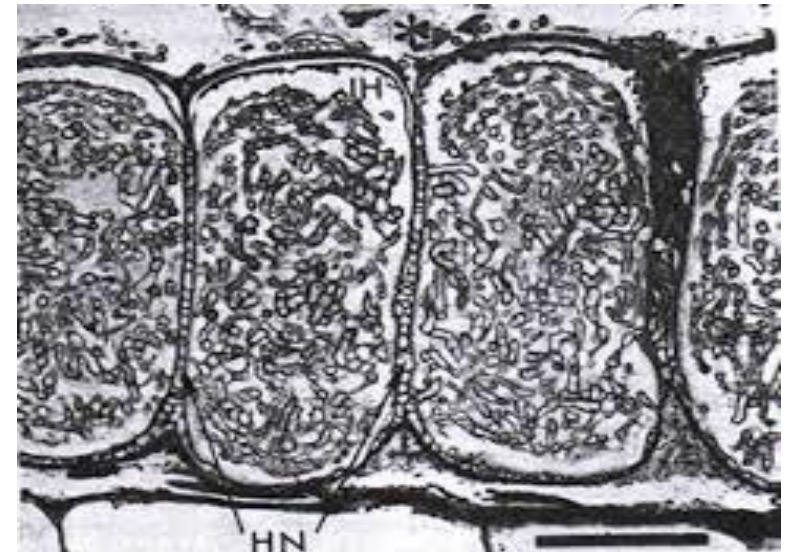
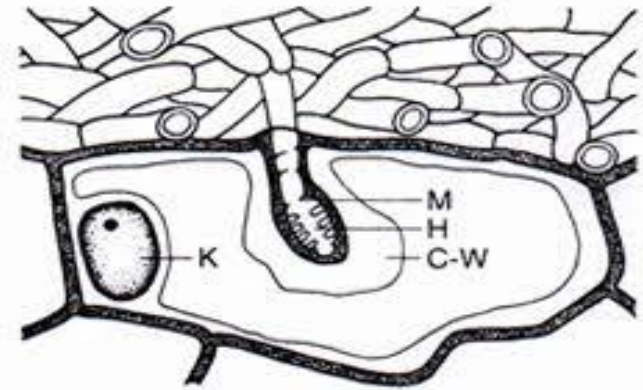


Monotropoid Mycorrhizae :

- The fungi belong to basidiomycotina, colonizing achlorophyllous members of angiosperms belonging to family monotropaceae. Fungal sheath present.

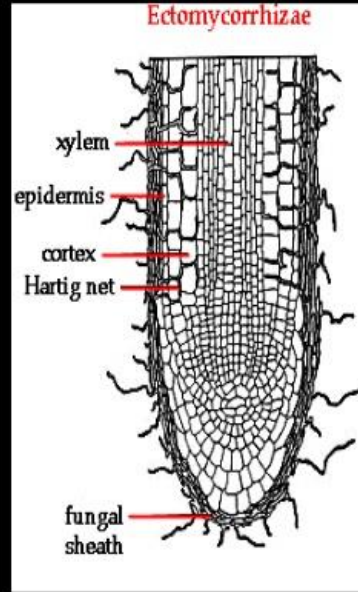
Arbutoid Mycorrhizae :

- Arbutoid mycorrhizal associations are variants of ectomycorrhizae found in certain plants in the ericaceae characterized by hyphae coils in epidermal cells.
- A major difference between the arbutoid and ectomycorrhizal association is that the hyphae of the former actually penetrate the outer cortical cells and fill them with coils.



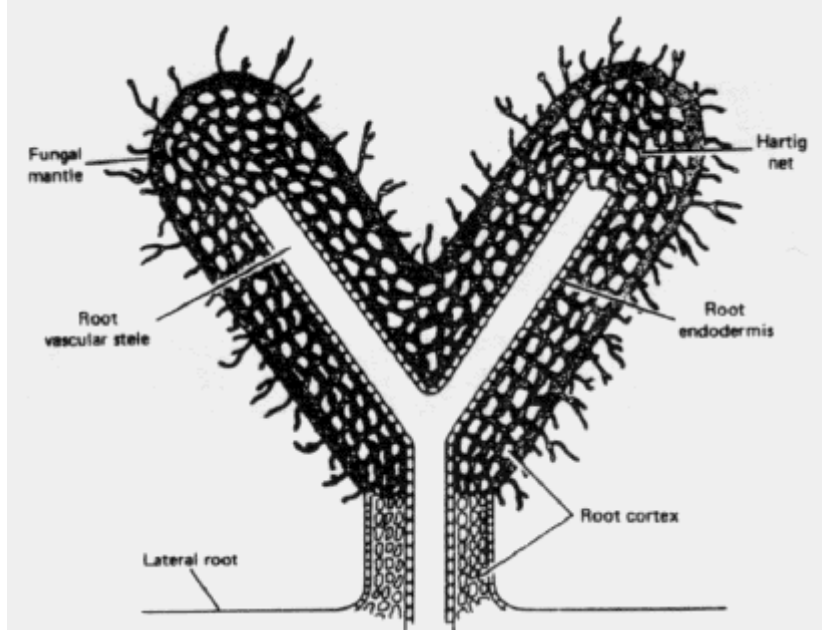
Ectomycorrhizae :

■ Ectomycorrhizae (ECM) are an association, where fungi form a mantle around roots. There is no hyphal penetration of cells. Fungal hyphae are generally separate. A distinct Hartig's net is present between the cells.



Hartig net is a network of inward growing [hyphae](#), that extends into the [root](#), penetrating between the epidermis and cortex of [ectomycorrhizal](#) plants. This network is a site of nutrient exchange between the [fungus](#) and the host [plant](#). The Hartig net is one of the three components required for [ectomycorrhizal](#) roots to form as part of [ectomycorrhizal symbiosis](#) with the host tree or plant. The Hartig net is named after [Theodor Hartig](#), a 19th-century German forest biologist and botanist. He reported research in 1842 on the [anatomy](#) of the interface between ectomycorrhizal fungi and tree roots.

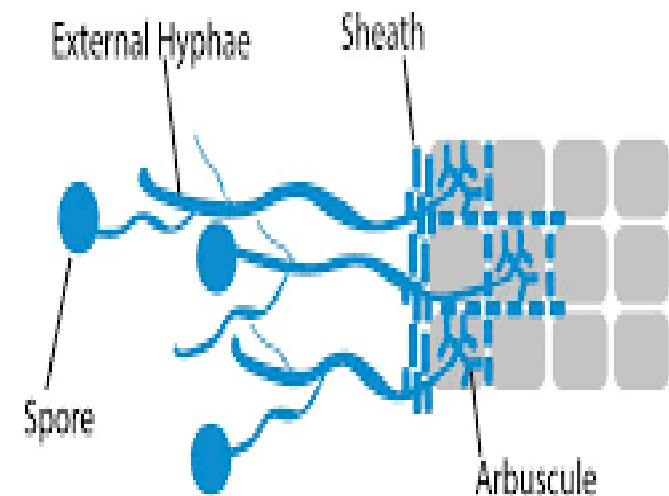
The Hartig net supplies chemical elements required for plant growth, such as potassium, and provides compounds, such as nitrate, used in combination with the ectomycorrhizal symbiosis for farmable crops, as well as certain kinds of lichens. Part of its role in mutualistic interactions is based on the chemicals it provides, as well as it being essential for bi-directional nutritional uptake, which has shown to help defend the fungi from heavy metal damage, amongst other benefits.



Ectendomycorrhizae :

- The fungi belong to Basidiomycotina, which covers both gymnosperms and Angiosperms plants. Ectendomycorrhizae show many of the same characteristics' of Endomycorrhizae but also show extensive intercellular penetration.
- The formation of Ectendomycorrhizae begins with formation of a hartig's net, which grows behind the apical meristem of the growing root. The hartig net penetrates between the epidermal and outer cortical cells and later extends to the inner cortex.

ECTENDOMYCORRHIZAE



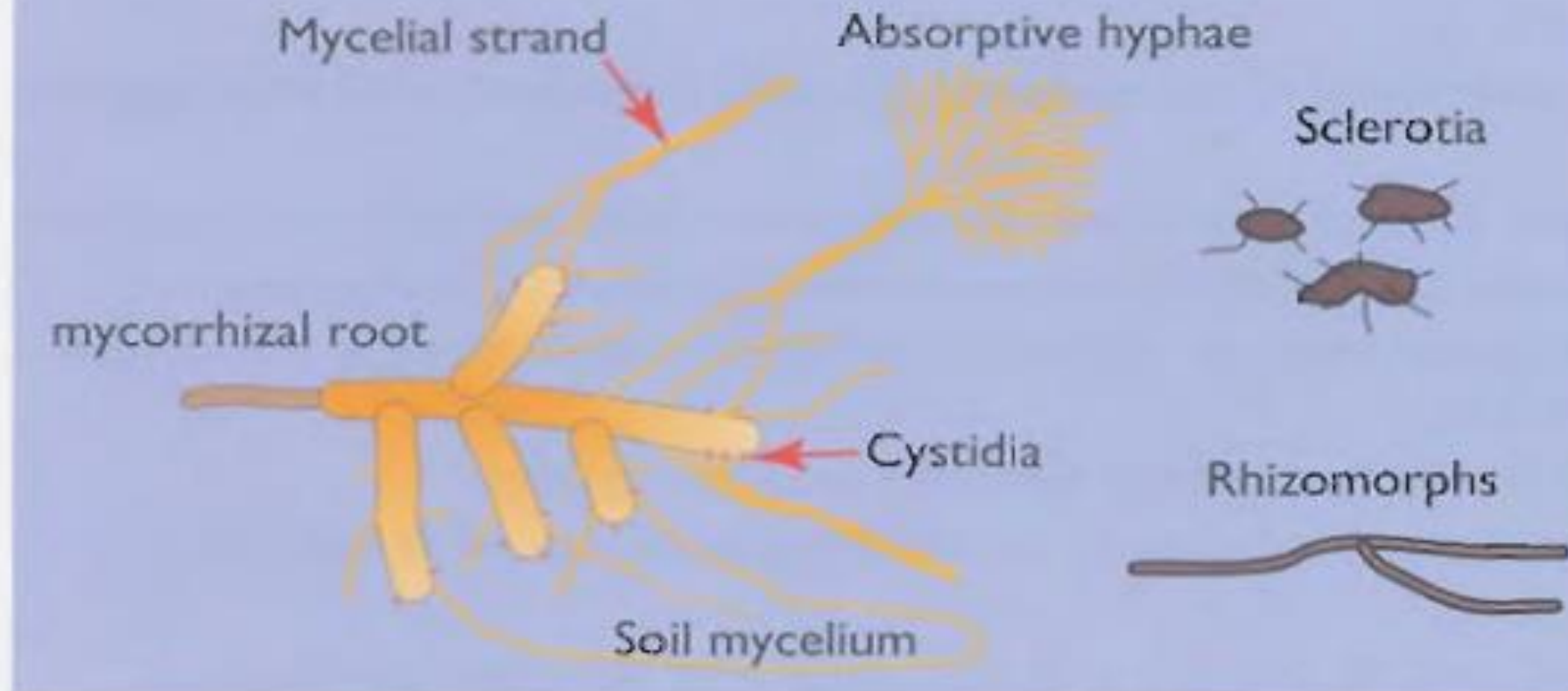
Applications of Mycorrhizae :

- Increase nutrient uptake of plant from soil.
 - P nutrition and other elements: N, K, Ca, Mg, Zn, Cu, S, B, Mo, Fe, Mn, Cl
- Increase diversity of plant.
- Produce uniform seedling.
- Significant role in nutrient recycling.
- More tolerant to adverse soil chemical constraints which limit crop production.
- Increase plant resistance to diseases and drought.
- Stimulate the growth of beneficial microorganisms.
- Improve soil structure.
 - Stable soil aggregate – hyphal polysaccharides bind and aggregate soil particles.

Cont...

- Increases absorption of phosphate by crops.
- uptake of zinc also increases.
- Increases uptake of water from soil.
- Increases uptake of sulphur from the soil
- Increases the concentration of cytokinins and chloroplast in plants.
- They protect plants during stress condition.

Mycorrhizal fungus structures in soil



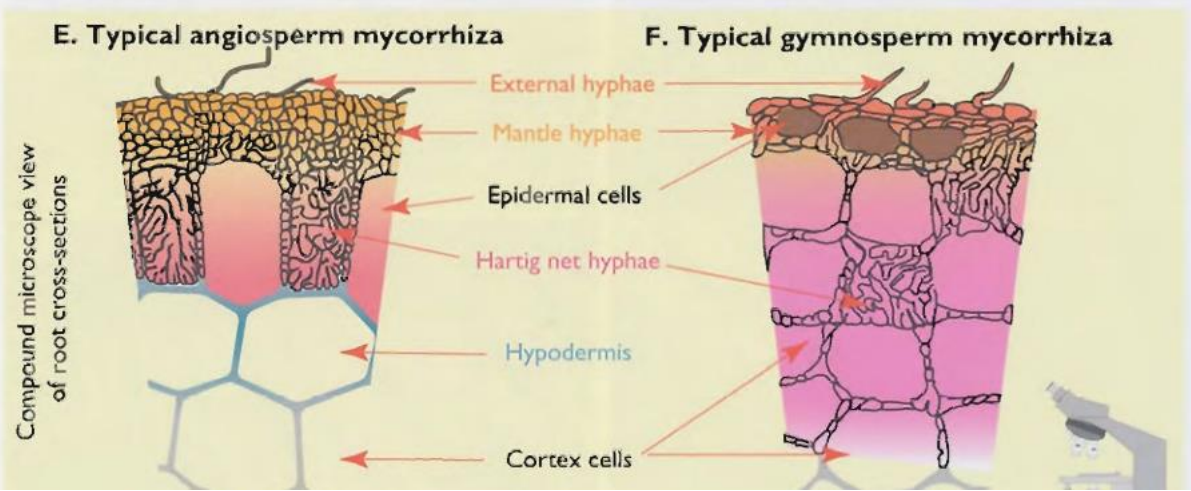
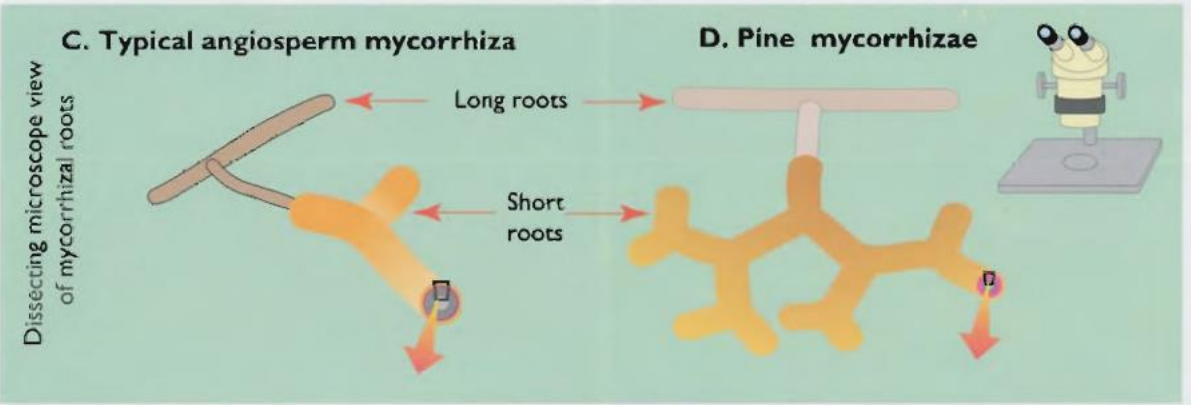
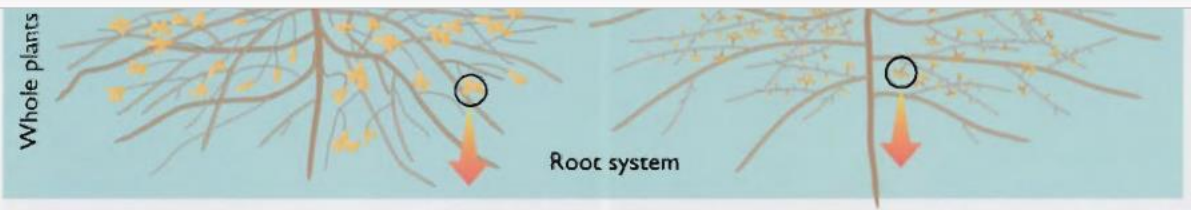


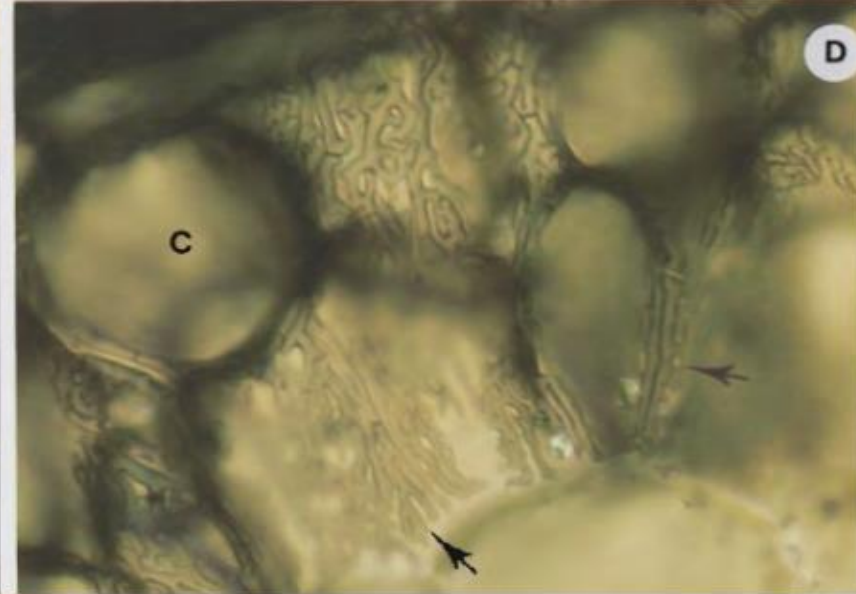
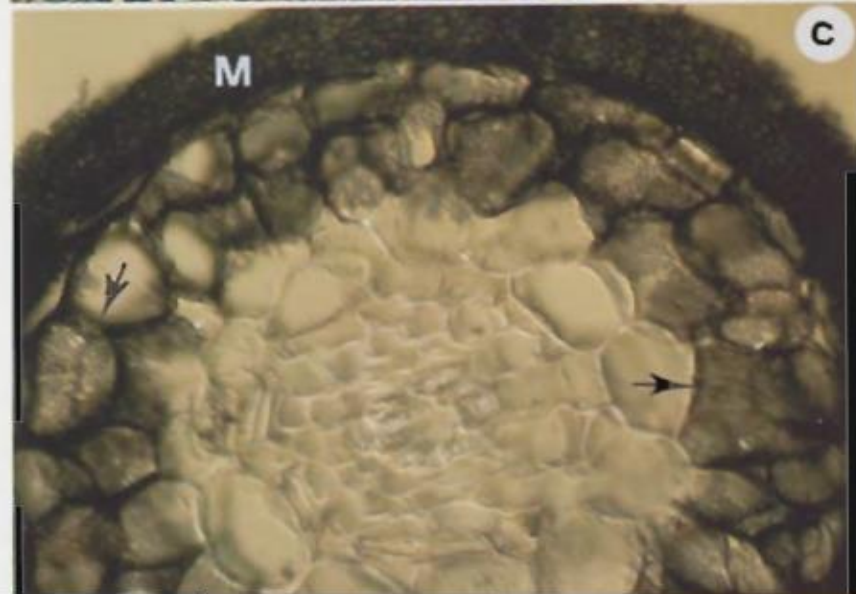
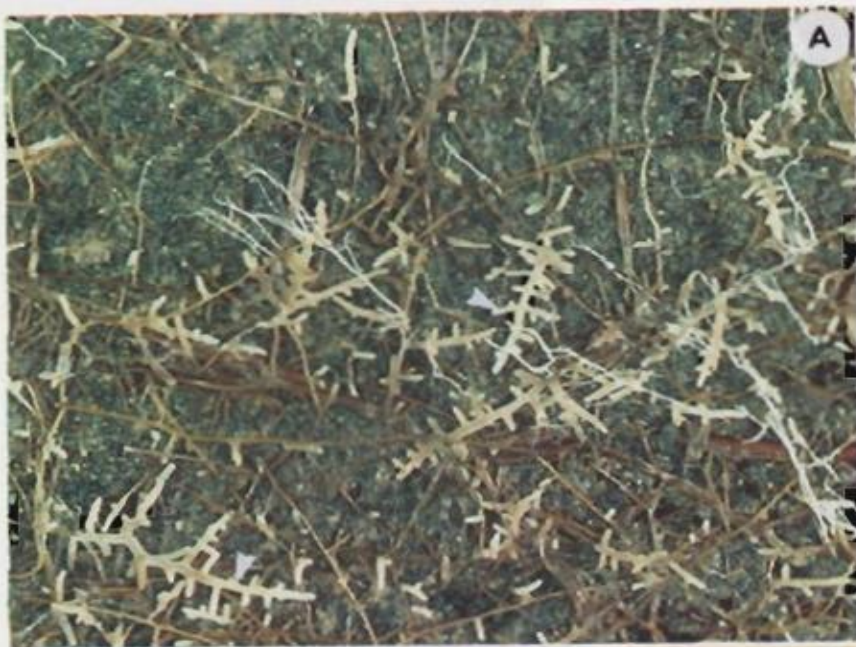
Conclusion :

Mycorrhizal association is very essential for the plants because it has several benefits like absorption of nutrients, increases drought resistance, enhance plant efficiency in absorbing water and nutrients from soil. Especially, AM fungi are very useful in the agriculture because it serves as biofertilizers as it helps in the absorption of phosphorus, and other nutrient uptake.

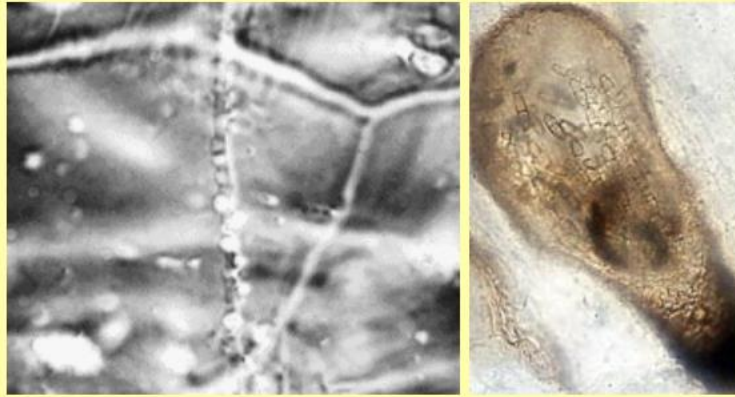
Table 1.4. The functional diversity of mycorrhizal fungi includes variations between individual species and isolates of fungi in the following capacities.

- A. Obtaining limiting soil nutrients:**
 - inorganic forms of phosphorus, nitrogen, etc.
 - organic forms of nitrogen, etc.
 - trace elements
 - B. Amelioration of adverse soil conditions due to:**
 - toxic concentrations of metal ions
 - extremes in pH
 - high conductivity (salinity)
 - nutrient imbalances such as high Mg:Ca ratios
 - C. Responses to severe climatic conditions:**
 - limited or excessive water supply
 - temperature extremes
 - D. Compatibility with different hosts**
 - E. Tolerance of adverse soil conditions:**
 - disturbance, microbial competition, etc.
 - F. Survival and spread in soil by spores, mycelia, etc.**
 - G. Capacity for inoculum production:**
 - spore production
 - growth in sterile culture (ECM)
 - growth in pot cultures (VAM)
-





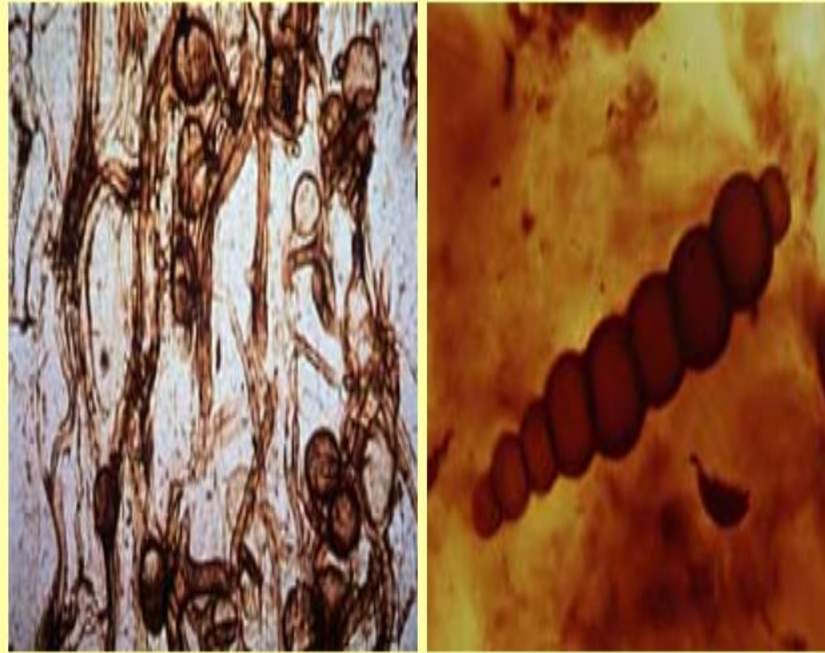
Fungi: Fossil Record



Fossil fungi : At left are fossil hyphae from the Cretaceous of northern France. The filaments resemble those of the living genus *Candida*. At right is a Miocene perithecium from Nevada. The fine preservation is due to the silicification of chert in which it was embedded.

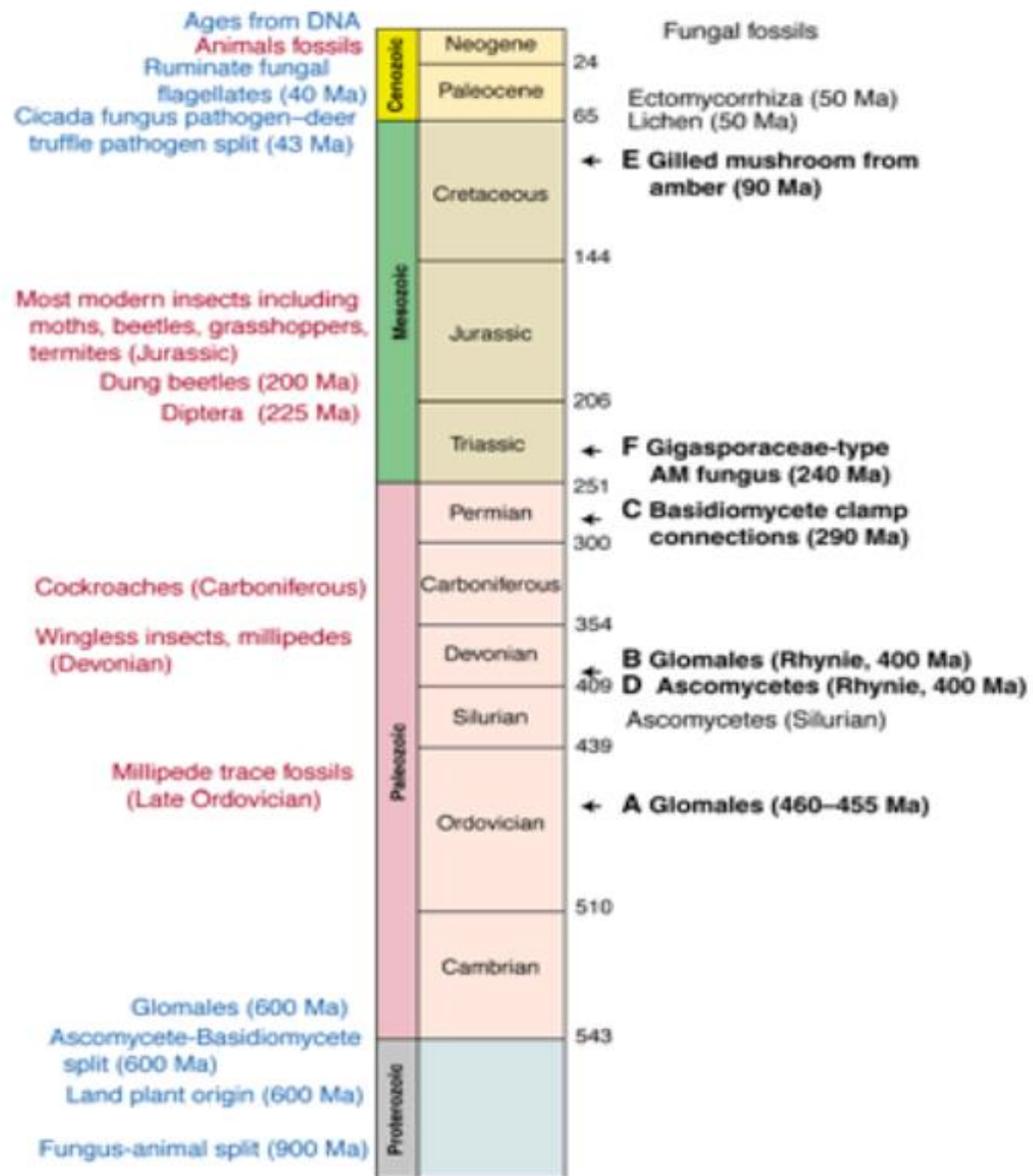
While fungi are not uncommon fossils, their fossils have not received a great deal of attention compared to other groups of fossils. Their fossils tend to be microscopic; very few large fungal bodies, such as mushrooms, have ever been found as fossils. Fossil fungi are often difficult or impossible to identify. The fungal filaments shown above at left are a case in point; found in [Cretaceous](#) amber from north France, they resemble living filaments of the common ascomycete *Candida*; however, since there is little information on how this fossil organism lived or how it reproduced (both important in recognizing modern taxa), its true affinities may never be known. By contrast, the [Miocene](#) fossil at right above has preserved the **perithecium**, an enclosed reproductive structure. Features of the spores and the perithecium in which they occur suggest that this may be a fossil species of *Savoryella*.

Recent careful studies of some well-preserved material have contributed much to our knowledge of fossil fungi. In particular, microscopic examination of fossil fungi from the [Devonian](#)-age [Rhynie Chert](#) in Aberdeenshire, Scotland, has shown that fungi and [land plants](#) were forming symbiotic relationships even at that very early stage in terrestrial evolution. In fact, all four major groups of modern fungi have now been found in Devonian strata, showing that the fungi had successfully invaded the land and begun to diversify before the first vertebrates crawled out of the sea!



More fossil fungi : At left is a section through a silicified stem of *Aglaophyton* from the Devonian Rhynie Chert. Among the cells are a fossilized fungus *Paleomyces*. At right are fungal spores from Lost Chicken Creek.

The oldest fossil fungi so far known are probably chytrid-like forms from the [Vendian](#) Period (Late Precambrian), found in north Russia. Older fossils of Precambrian "fungi" are now usually considered to be empty sheaths of filamentous [cyanobacteria](#), or else are not distinct enough to be placed in any taxon with certainty. Fossil fungi older than the Devonian are rare; the fungi may have undergone an evolutionary radiation at about the same time that the land plants began to radiate.



PALEOMYCOLOGY – STUDY OF FOSSIL FUNGI

INTRODUCTION

Paleomycology is not a new science. Sternberg's descriptions, in 1820, of the first fungi, among the smallest of fossils, precede the naming of some of the largest—the first dinosaurs. Admittedly his *Algacites* and *Carpolites* were not intended for fungi, but they contained descriptions of what was later claimed to be a carpophore and rhizomorphs of Basidiomycota. The credit for the first conscious attempts to record fossil fungi must go to Eichwald and to Lindley & Hutton who, in 1830 and 1833, described the polypores *Daedalea volhynica* and *Polyporus bowmanii*. The identity of the former is obscure; the latter was soon identified as a fish scale. In 1836 Göppert described indeterminate specks on fronds of a Carboniferous fern as *Excipulites neesii*, setting a precedent for unfounded conclusions that, continued in the work of others, brought the number of similar fossil genera to 20 by the mid-nineteenth century. They were given both fossil and modern generic names, and matched with living pyrenomycetes, discomycetes, and coelomycetes.

FOSSIL RECORD

Proterozoic: Dawn of Oomycota

The concept of Precambrian life is relatively new, but it included fungi from its inception: coenocytic hypha-like filaments associated with stromatolitic blue-green algae. Some, assigned to *Eomycetopsis*, were found in the Middle and Upper Precambrian of most continents; others, as partners of a presumed lichen-like association, are held responsible for the extraction and deposition of South African gold some 2.3–2.7 billion years ago (28). Although the fungal affinity of these filaments is far from proven, there is no reason, judging by later events, to question the existence of Oomycotan water molds in the early Proterozoic, or to dispute their place among the first eukaryotes. The Late Precambrian “ascus-like microfossil” (50) is a perfect match for textbook illustrations of intercalary oogonia of modern Saprolegniaceae.

Early Phanerozoic: Age of Marine Oomycota and Chytridiomycota

The occurrence of saprolegniaceous water molds in ancient marine environments has been on record since the 1850s. A relative of the modern *Leptolegnia marina* may have been responsible for tubular borings in shells and scales of arthropods and fish since Early Cambrian (58). *Ordovicimycetes*, showing both Oomycotan and algal affinities, grew in Ordovician bryozoa. *Palaeachlya silurica* allegedly parasitized Silurian and Devonian corals, though its frequent and specific association might perhaps indicate a mutualistic rather than a parasitic relationship.

Devonian: Terrestrial Symbiotic Oomycota

Among the ancient inhabitants of calcareous marine metazoa were forms (17) that appeared in the Early Devonian, in some of the earliest vascular plants. Describing these vesicular, coenocytic, endophytic hyphae as *Palaeomyces gordonii* and *P. asteroxylii*, Kidston & Lang noticed their similarity to the modern endotrophs and suspected a symbiotic association—a view that has since acquired new evidence and supporters (9, 14). Pirozynski & Malloch (44) went a step further by postulating the mycotrophic origin of vascular plants, which they consider to be a highly evolved alga/fungus partnership. Given the new role, the fungus becomes less of a paradox: obligately endophytic, yet ubiquitous in host range and geographic distribution, unchanged morphologically despite profound climatic and floristic changes—one of the oldest organisms known that “undoubtedly occupies a unique archaeological niche which entitles it to be termed a living fossil” (63). Today, performing its half a billion-year-old function, it still supports the vast majority of living plants, including our crops. Unfortunately it is rarely recognized that crop plants that “cannot provide their own fertilizer” are not the unsolved problem of millenia of agricultural practice, but their result—the result of perennial disregard of the sustaining function of the less conspicuous fungal component.

Carboniferous: Endomycorrhizae; Parasitic Oomycota and Chytridiomycota; Appearance of Zygomycota and Basidiomycota

The discovery of *Mycorrhizonium*, a psilopsid rhizome harboring the familiar endophyte (61) stimulated other investigators to demonstrate the presence of fungi, sometimes in the form of endomycorrhizae, in lepidodendrons, calamites, ferns,

and cordaites (1, 14, 37). The symbiotic nature of much of the Carboniferous flora seemed to be established, and a wish was expressed that the fossil record of the fungal component "may continue to reveal significant fragments of their [plants'] ancestral development" (3). Others, however, saw the fungi in the role of parasites or saprophytes (4), or were prevented from accepting the fungi as mycorrhizal because of their caulicolous habit. But the death of the photosynthetic partner need not prevent a fungus from persisting in the decomposing tissues, and as far as their systemic habit is concerned we should remember the modern *Psilotum*, in which the symbiotic endophyte occurs both in the gametophyte and the sporophyte.

While Polyporales appear to be well established in the Mesozoic and their presence in the Carboniferous indicated, the other major group of homobasidiomycetes, the Agaricales, are conspicuous by their absence from the fossil record. This is not unexpected if one considers the unsuitability of fleshy carpophores for fossilization, and the inability of most basidiospores to withstand acetolysis (27). It is true that two species of *Agaricites* were described from the Miocene, but the names given to hyphae preserved in wood in the one case, and a mushroom-shaped fossil in the other, do not indicate affinities. The agarics may not be as old as the polypores but we should nevertheless look for their pioneers in the Mesozoic. To James (32) the proof of their former existence was "in the remains of insects that live upon fleshy fungi to exclusion of all other substances." To me, the Mesozoic origin of Agaricales is indicated by their present-day involvement in secondary ectotrophic symbioses, for these may have led to the evolution of the Pinaceae, whose success in conquering boreal Laurasia was not paralleled in the already separated Gondwana (D. Malloch, personal communication).

Cenozoic: Age of Ascomycota

The Cretaceous families as well as new groups of superficial leaf Ascomycota appear early in the Tertiary. Some can be confidently matched with living representatives on account of their distinctive mycelium or fructifications, and an often excellent state of preservation. The records of foliicolous fungi were compiled by Dilcher (22), who demonstrated the presence in Eocene Tennessee of essentially modern *Asterina*, *Asterolibertia* (*Asterina nodosaria*), *Patouilliardiella*, *Meliola*, and *Euthalopycnidium* (*Trichopeltinites*). Further studies led to the transfer of his *Shortensis memorabilis*, first into the modern *Manginula* (35), and then to *Vizella* (51), but I consider it conspecific with *V. oleariae* despite 50 million years of evolution on a different continent and readaptation to a host which evolved subsequently. His *Pelicothallos villosus* appears to be the green alga *Cephaleuros virescens*, and his *Sporidesmium henryense* is a good match for *Hansfordiella asterinarum*, which is still associated with *Asterina* as its parasite.

Among other groups, the powdery mildews *Uncinulites* and *Erysiphites* (42) are Ascomycota, the latter perhaps even Erysiphaceae, but the evidence is insufficient for accurate disposition. What has been identified as *Microsphaera*, *Phyllactinia*, and *Uncinula* (38) turns out to be dinophytan cysts. Setose and lobed bodies assigned to two modern genera of Chytridiomycota (11) resemble developing fructifications and juvenile conidiophores of certain leaf-litter hyphomycetes, or appressoria of, for example, *Gaeumannomyces*. Perithecia and pycnidia of unspecialized saprophytes such as *Chaetomium* and *Chaetomella* (42), and less distinctive ostiolate or astomous fruit bodies (38), have also been found.

Apothecia of discomycetes and perithecia of wood-inhabiting stromatic Sphaeriales were already recognized from Cenozoic remains in the first half of the nineteenth century. These finds are now known to correspond to modern *Hypoxylon*, *Rosellinia*, and *Trematosphaeria* (55, 62). The lignicolous *Cryptocolax clarensis*, with both the cleistothecia and conidia preserved, not only matches but antedates the description of the living *Xylogone sphaerospora*.

Amber has long been the source of excellently preserved hyphomycetes: *Paecilomyces* (8), *Cladosporium*, *Gonatobotrys*, *Torula* (16), and others whose proper identity could no doubt be established by reexamination of the original specimens.

EVOLUTION OF FUNGI

Origin and Evolution of Fungi

A. Algal Origin of Fungi : There are two school of thoughts :

(a) Polyphyletic Origin : It was proposed by Pringshein (1858), Cohn (1872), Sachs (1875), C.E. Bessey (1895), Harper (1899), E.A. Bessey 1935, 1955), *et al* grouped the fungi into heterogenous organism evolved from groups of algae by the loss of chlorophyll. They suggested that the *Chytrids* evolved from unicellular algae; the *Saproleginales* evolved from *Oedogonium* and *Vaucheria*; the *Zygomycetes* evolved from *conjugales*; and the *Ascomycetes* and *Basidiomycetes* evolved from red algae.

(b) Monophyletic Origin : De Barry (1881) proposed that algae and fungi derived from a unicellular; non-green organisms in more or less parallel line. Fischer (1892) and Alkinson (1909) supported this theory.

B. Protozoan Origin of Fungi : Gobi (1884) was first proposed to this theory later supported by many Mycologist.

Origin of Flagellated Phycomycetes

A. Algal origin of flagellated phycomycetes

Sach's view : There is great affinity between *Sapronlegnia* like member of oomycetes and *Vaucheria* like member of green algae.

Bessey's view : The lower phycomycetes were derived from some coccoid algae of Xanthophyceae. These algae give three different series of fungi. *Chytridaceous fungi* have single posterior flagella, *Hypochytridaceous fungi* have single anterior flagella, and *oomycetes* retains both types of flagella.

Gaumann's view : He suggested that oomycetes (Saprolegniaceae, Peronosporaceae and Leptonitaceae) are derived from siphonales (algae).

B. Ptozoan Origin of Flagellate Phycomycetes : Some suggested that chytrids evolved from uniflagellate protozoa and biflagellate phycomycetes evolved from biflagellate protozoa.

The origin of non-flagellated phycomycetes (zygomycetes) as believed to be from algae. The zygomycetes directly evolved from green algae similar to modern conjugating *Spirogyra*. Other suggested that zygomycetes evolved from certain saprolegniales.

Origin of Ascomycetes

There are two view regarding the origin of ascomycetes

(i) Floridean hypothesis (Sach's, 1875) : This hypothesis is based on similarity between reproductive structure and process involve sexual reproduction in Ascomycetes and those of florideae, e.g. presence of trichogyne, non motile male gametes, branches around female reproductive organ (ascogenous hyphae in ascomycetes and carposporic branches in red algae).

(ii) Phycomycetous hypothesis (De Bary, 1887) : This Hypothesis support the origin of ascomycetes from certain zygomycetes. Some consider Endogonaceae (zygomycetaceae) as possible ancestor to give rise to *Dipodarcus (Ascomycete)*.

The origin of Basidiomycetes is consider from ascomycetes is due to similarity in clamp connection in Basidiomycetes with the crozier formation in Ascomycetes.