Mycorrhiza Fungi

Mycorrhiza

- **Mycorrhizae literally translates to "fungus-root"**
- **Vitadini (1842) was the first to recognise the possible beneficial role of fungal mycelia which mantle the root of higher plants, and this association is named as mycorrhiza (pl. mycorrhizae) i.e., the fungal root, by Frank (1885)**
- **Mycorrhiza defines a mutually beneficial relationship between the root of a plant and a fungus that colonizes the plant root**
- **Thus mycorrhizae are the symbiotic associations between plant root and fungi, with bidirectional nutrient exchange between the partners**
- **This exchange is a significant factor in nutrient cycles and the ecology, evolution, and physiology of plants**

- **About 90% of all land plants are associated with mycorrhiza**
- **The mycorrhizal association is not available in Cruciferae, Chenopodiaceae and Resedaceae**
- **In some cases, the relationship is not mutually beneficial, sometimes, the fungus is mildly harmful to the plant, and at other times, the plant feeds from the fungus**
- **In environments in which water and nutrients are abundant in the soil, plants do not require the assistance of mycorrhizal fungi, nor might mycorrhizal fungi germinate and grow in such environments**

Features of Mycorrhization

Scannerini (1988) briefly pointed out the common features of mutualistic symbionts

These include:

(i) Absence of any phytopathological symptoms in the partners during the active phase of mutualism

(ii) Presence of complex interfaces between cells of the partners with a predominant type of perisymbiotic membrane, surrounding intracellular symbionts

(iii) Presence of various types of phagocyte-like structures during establishment of symbionts and during harvesting phase to control the symbiotic population by the host

Types of Mycorrhizae

There are two predominant types of mycorrhizae: Ectomycorrhizae, and Endomycorrhizae

Peterson and Farquhar (1994) classified the mycorrhizae into seven (7) distinct types

These are :

(1) Ectomycorrhizae

(2) Vesicular-arbuscular mycorrhizae (VAM)

(3) Ectendomycorrhizae (Arbutoid)

(4) Ericoid mycorrhizae

(5) Centianoid mycorrhizae

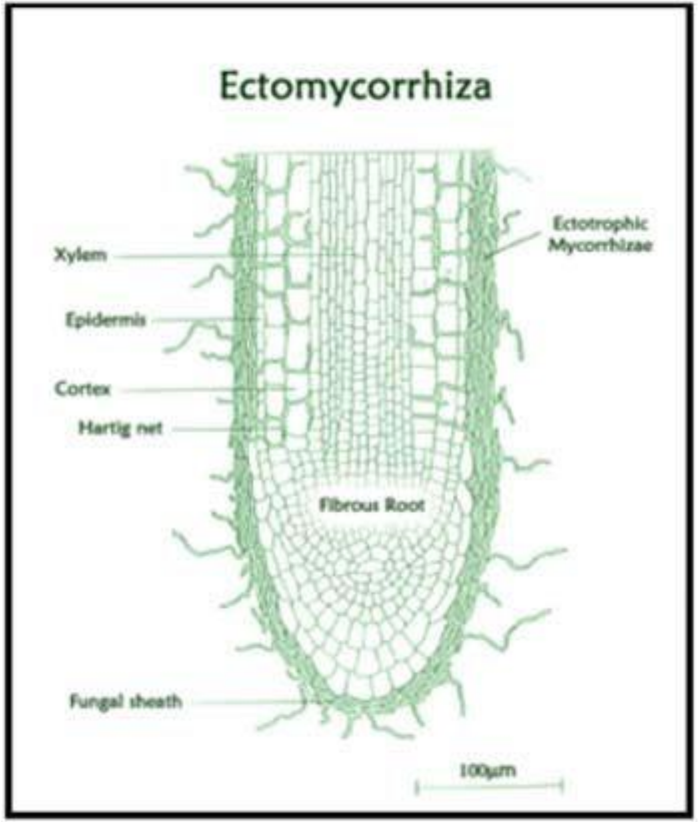
(6) Orchidoid mycorrhizae

(7) Monotropoid mycorrhizae

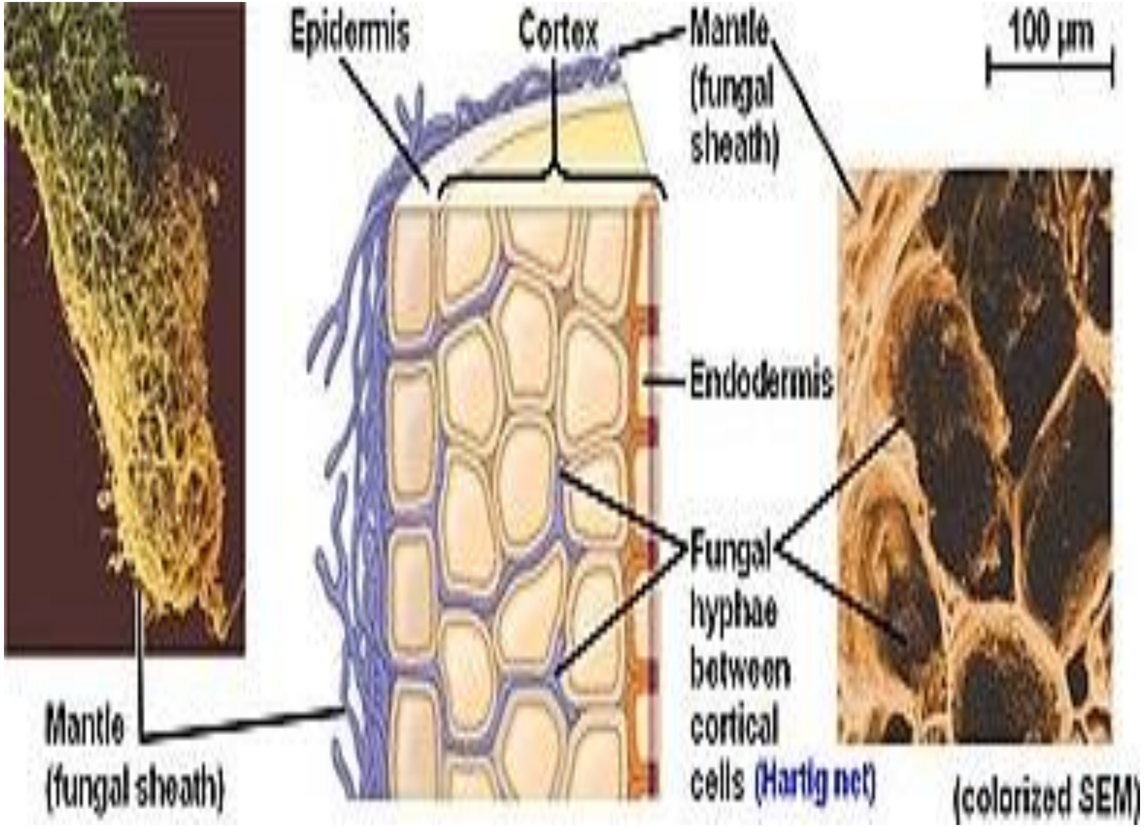
A. Ectomycorrhiza

- Ectomycorrhiza is commonly called “sheathing mycorrhiza”
- This kind of relationships are characterized by an intercellular surface known as the Hartig Net
- The Hartig Net consists of highly branched hyphae connecting the epidermal and cortical root cells
- Additionally, ectomycorrhiza can be identified by the formation of a dense hyphal sheath surrounding the root’s surface which is known as the mantle, with varying thickness
- Generally they cause extensive branching and growth of roots and modification of branching pattern, such as racemose type in dicots (Fagus) and dichotomous in gymnosperms
- The fungus enters the cortex forming ‘Hartig net’, but never goes inside the endodermis or stele

- **Overall, only 5-10% of terrestrial plant species have ectomycorrhiza**
- **Ectomycorrhiza tend to form mutual symbiotic relationships with woody plants, including birch, beech, willow, pine, oak, spruce, and fir**
- **They appear in various colours like white, brown, yellow, black etc., depending on the colour of the fungus**
- **Majority of the fungi belong to Agaricales of Hymenomycetes under Basidiomycotina**
- **More than 100 species of toadstools are reported to form mycorrhiza**
- **Most of the members are belonging to the genera Amanita, Tricholoma, Boletus, Russula, Lactarius etc.**
- **Members of Gasteromycetes under Basidiomycotina like Rhizopogon and Scleroderma are also involved in this process**
- **Some members of Ascomycotina like Gyromitra esculenta, all species of Tuber (T. melanospora) form mycorrhizae**



Ectomycorrhiza
Xylem
Epidermis
Cortex
Hartig net
Ectotrophic Mycorrhizae
Fibrous Root
Fungal sheath
100µm



Epidermis
Cortex
Mantle (fungal sheath)
100 µm
Endodermis
Fungal hyphae between cortical cells (Hartig net)
Mantle (fungal sheath)
(colorized SEM)

B. Endomycorrhiza

- Endomycorrhizae are found in over 80% of extant plant species - including crops and greenhouse plants such as most vegetables, grasses, flowers, and fruit trees
- Endomycorrhizal relationships are characterized by a penetration of the cortical cells by the fungi and the formation of arbuscules and vesicles by the fungi
- These have an exchange mechanism on the inside of the root, with the fungi's hyphae extending outside of the root
- It is a more invasive relationship compared to that of the ectomycorrhiza
- Endomycorrhiza are further subdivided into specific types: Arbuscular Mycorrhizae, Ericaceous Mycorrhizae, Arbutoid Mycorrhizae, and Orchidaceous Mycorrhizae

Vesicular-arbuscular mycorrhizae (VAM)

- It is a type of endomycorrhizal association, where both vesicles and arbuscles are developed together
- The association appear to be obligate symbiont and most of the members are not culturable
- VAM is by far the commonest of all mycorrhizae and has been reported in more than 90% of land plants
- They are found in bryophytes, pteridophytes, gymnosperm (except Pinaceae) and most of angiosperms, commonly in Leguminosae (Fabaceae), Rosaceae, Gramineae (Poaceae) and Palmae (Arecaceae)
- VAM has even been reported in Lower Devonian plant, Rhynia also
- VAM is produced by aseptate mycelial fungi belong to Endogonaceae under Mucorales of Zygomycotina and those members produced zygospores
- The important genera involved in VAM are Glomus, Gyrospora, Acaulospora etc.

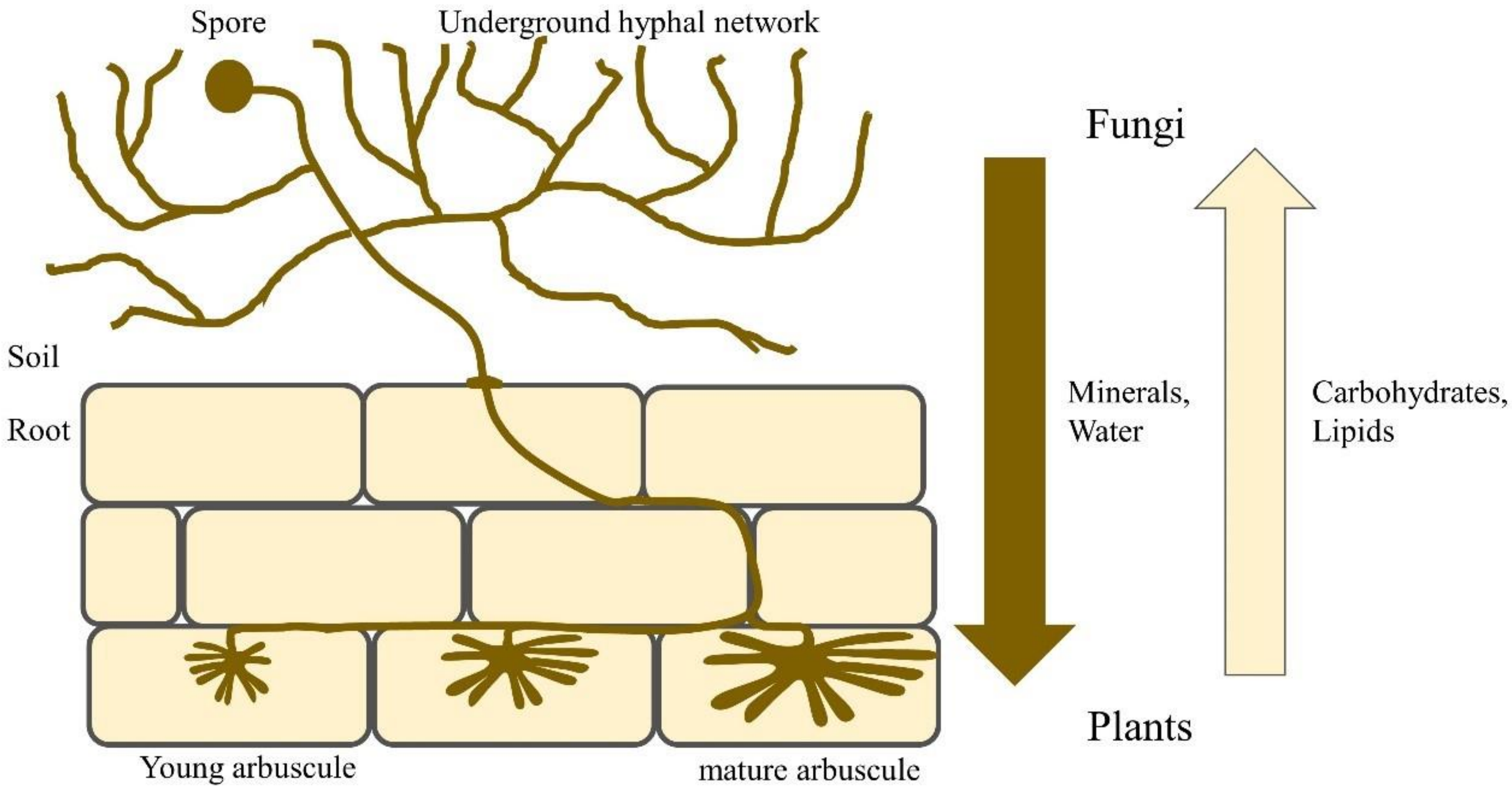
The VAM is so named because of the presence of two characteristic structures i.e., vesicles and arbuscles:

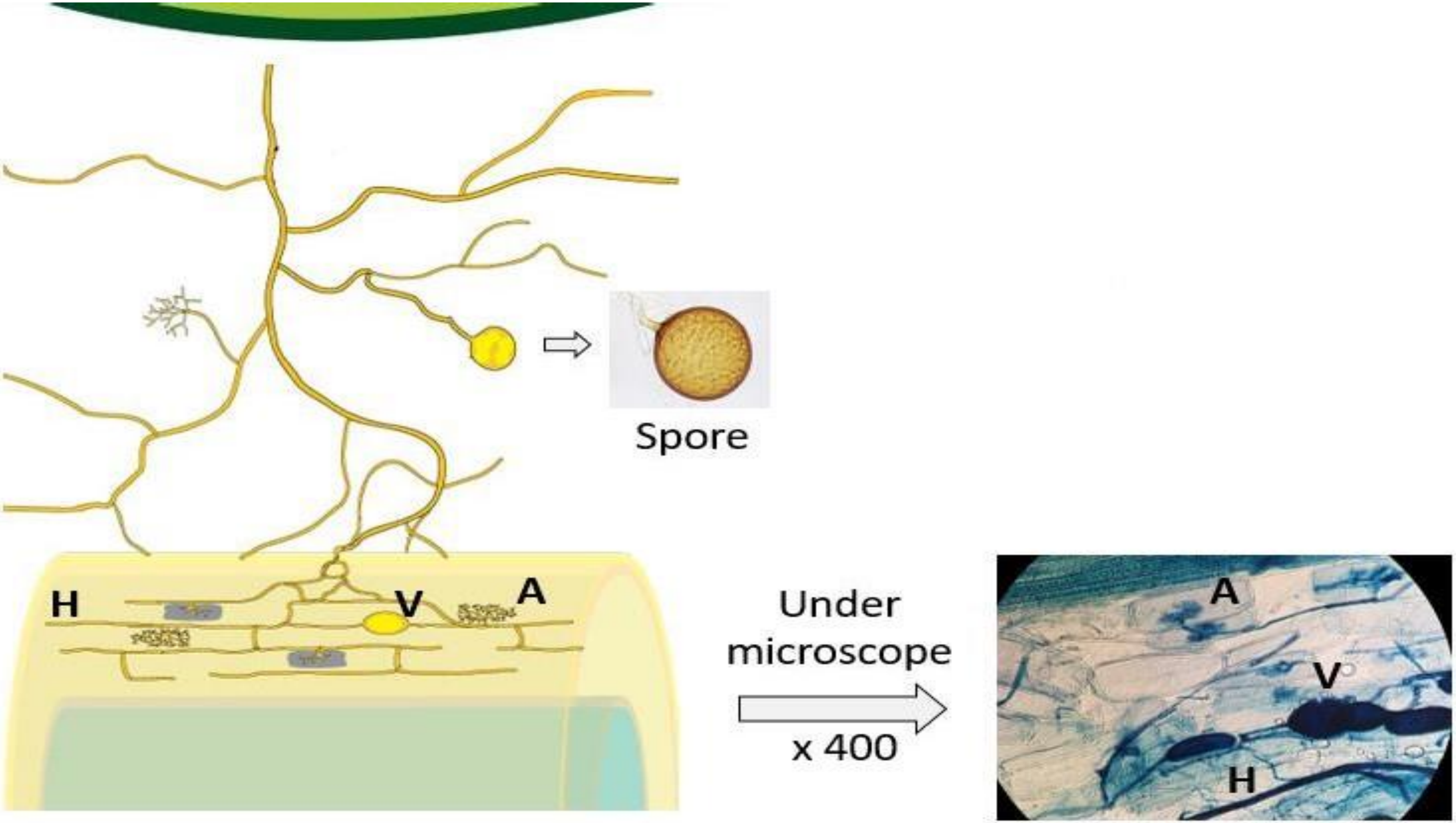
(i) The vesicles are thin or thick walled vesicular structures produced intra-cellularly and stored materials like poly-phosphate and other minerals

(ii) The arbuscles are repeated dichotomously branched haustoria which grow intracellularly

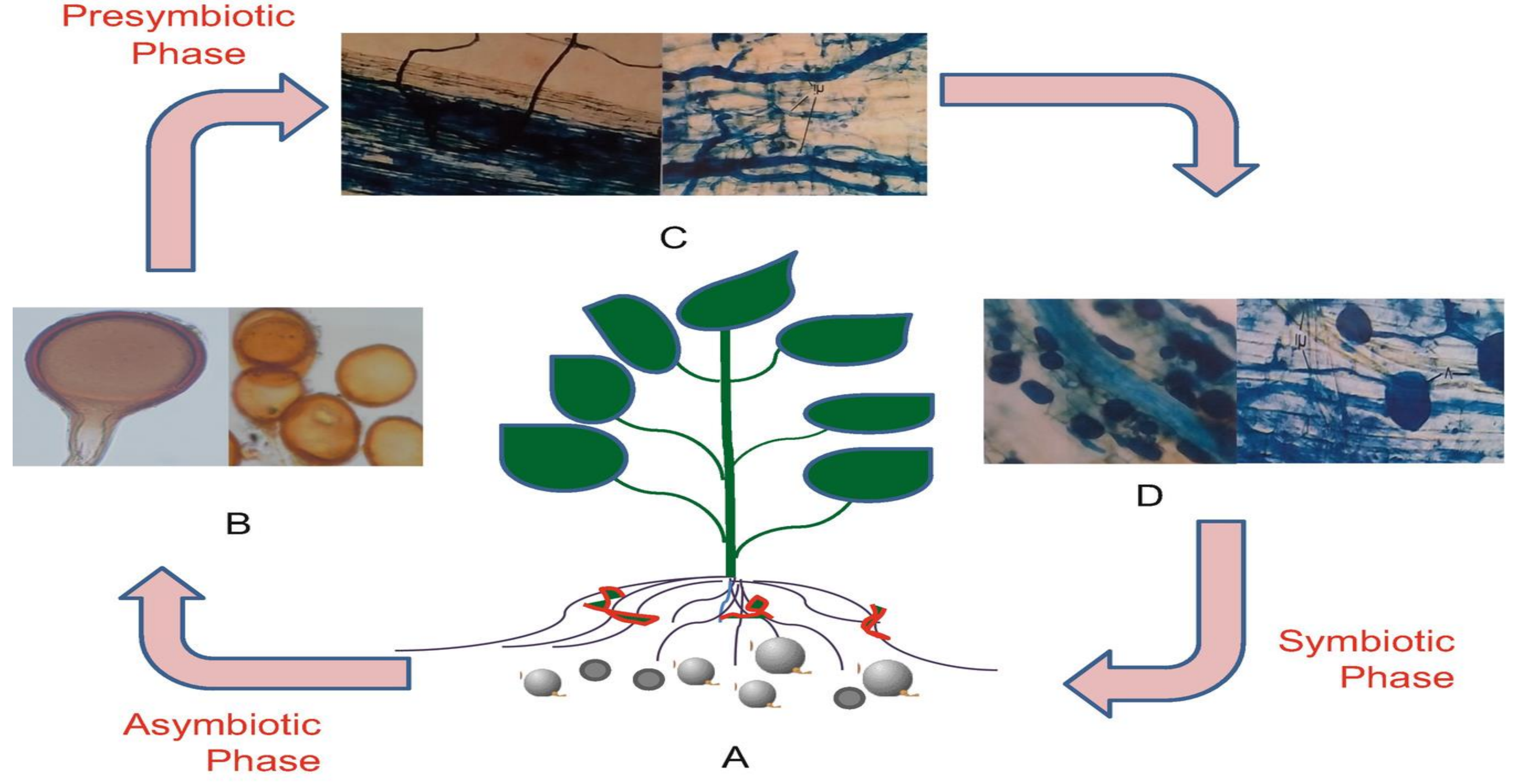
- **The arbuscles live for four days and then get lysed releasing the stored food as oil droplets, mostly polyphosphate**
- **There is no fungus mantle, but only a loose and very sparse network of septate hyphae spread into the soil**
- **These hyphae bear different types of spores, chlamydospores, or aggregation of spores in sporocarp or zygospores**

- **The superficial hyphae bear branches that penetrate the epidermis and then grow intercellularly only in cortex**
- **Intercellular hyphae form arbuscles inside the parenchyma of cortex by repeated dichotomous branching of the penetrating hyphae**
- **The cell membrane of the penetrated cell is invaginated and covers the arbuscles**
- **The hyphae also develop both inter- and intracellular thick-walled vesicles**
- **The chlamydospores may germinate on nutrient agar, but the hyphae stop growing when food inside the spore is used up, thus they cannot be subcultured**


Spore
Underground hyphal network
Fungi
Soil
Root
Minerals,
Water
Carbohydrates,
Lipids
Plants
Young arbuscule
mature arbuscule



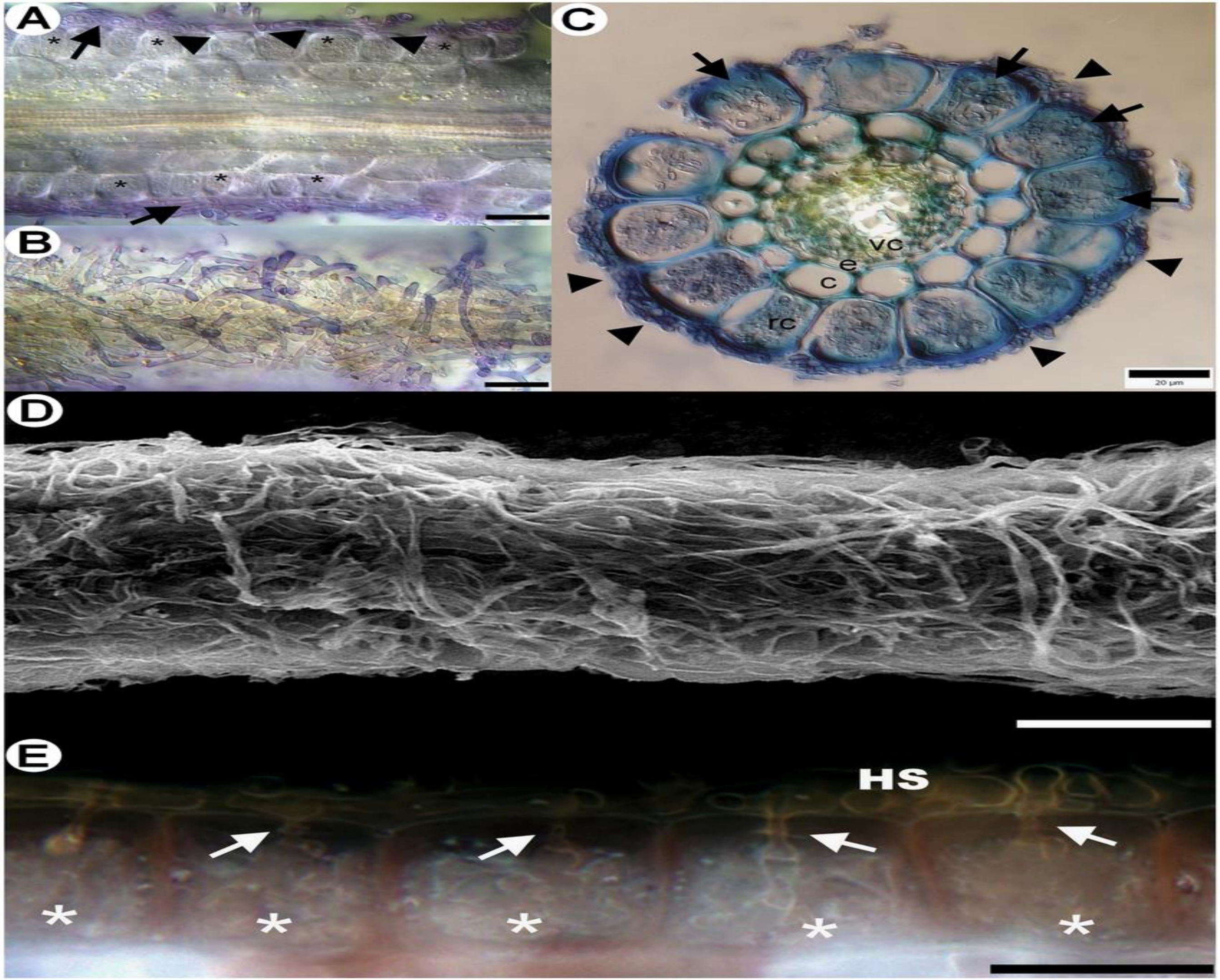
Spore
H
V
A
Under
microscope
x 400
A
V
H

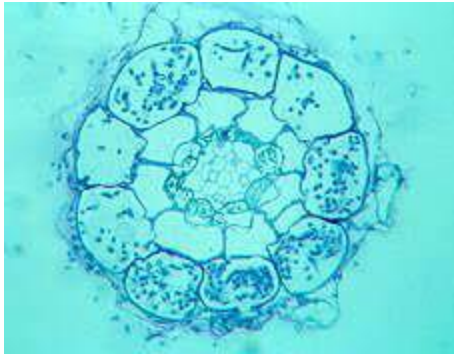


Propagation cycle of arbuscular mycorrhizal fungi

Ericoid mycorrhizae

- Ericoid mycorrhizae are found in the different members of Ericaceae like Erica, Calluna, Vaccinum, Rhododendron etc.
- The fungi are slow-growing, septate and mostly sterile
- They are mostly culturable
- Both Pezizella ericae (Ascomycotina) and Clavaria vermiculata (Basidiomycotina) have been isolated from Rhododendrons
- During this association the rootlets of the plants are covered by very sparse, loose, dark, septate hyphae that penetrate the cortex forming intercellular coils
- After 3-4 weeks the coils degenerate like arbuscles of VAM
- Most of the members of Ericaceae grow in acid soil with less amount of P and N nutrition
- The fungus gets the photosynthate from the host and improves the mineral uptake and nutrition of the host, especially P and N


A
B
C
vc
e
c
rc
20 µm
D
E
HS



Ectendomycorrhizae (Arbutoid)

- **Some members of the family Ericaceae and members of other families of Ericales have mycorrhizae intermediate in form between ecto- and endomycorrhizae types, called ectendomycorrhizae**
- **Arbustus and Arctostaphylos of Ericaceae show this type of mycorrhizal association**
- **In Arbustus, the root system is differentiated into long and short roots**
- **The short roots are swollen and covered by hyphal mantle**
- **Hartig net is absent in this association, but intercellular coils develop in the outer cortical cells**
- **The hyphae penetrate the cortical cells of plant roots, differentiating it from ectomycorrhizal fungi**
- **Nothing is known about the fungi involved in this association**

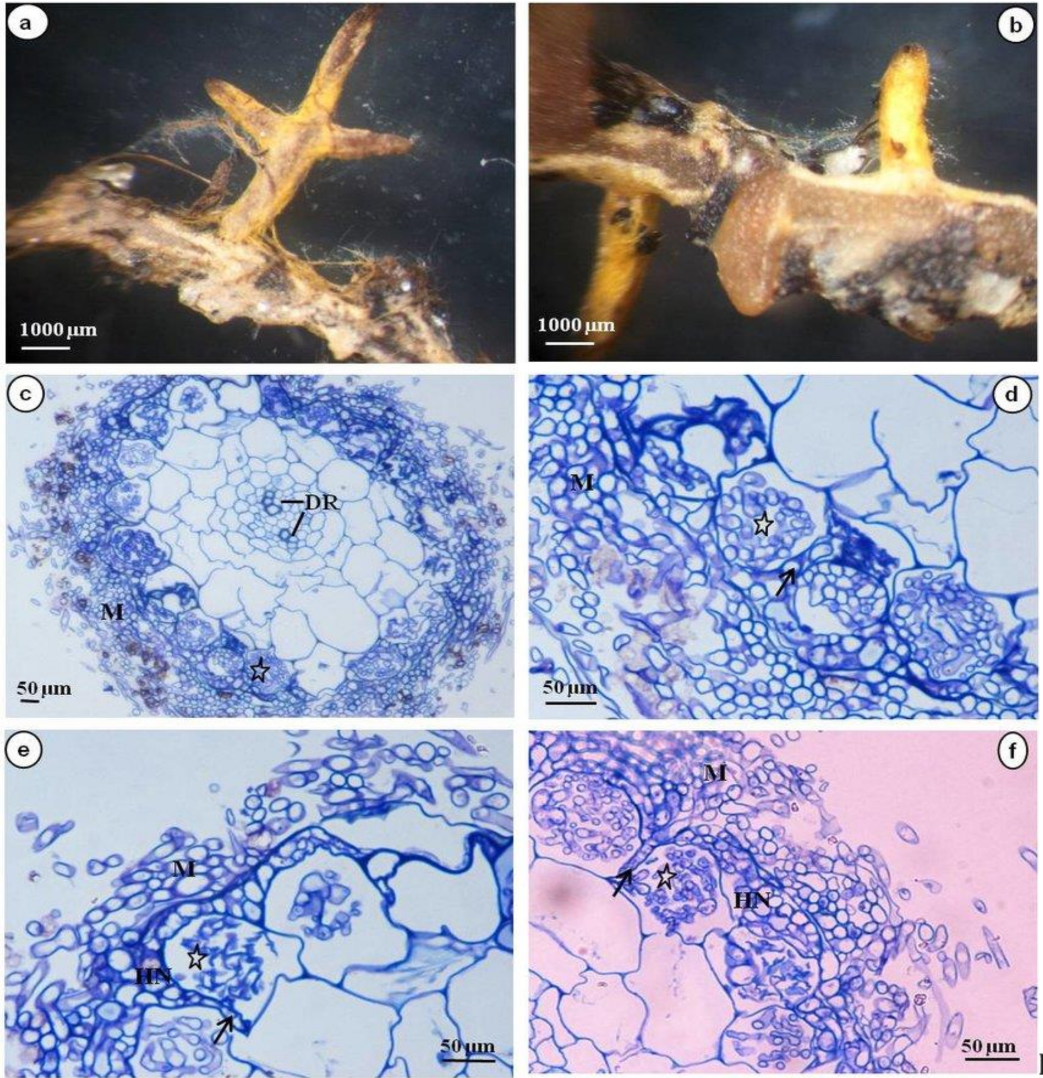


Figure 179. Diagram showing main features of an arbutoid mycorrhiza. A mantle (M), paraepidermal Hartig net (arrov

Gentianoid mycorrhizae

- Seedlings of some members of Gentianaceae (Biackstonia perfoliata, Gentianella amarella, etc.) get infected within 2 weeks of germination
- In root, the cortical cells become full of irregular coils of aseptate hyphae
- With time the hyphae become lysed
- Vesicles are occasionally seen attached to these coils

Orchidoid mycorrhizae

- **Orchid seeds require fungal invasion in order to germinate because, independently, the seedlings cannot acquire enough nutrients to grow**
- **Orchids produce millions of tiny seeds per capsule, weighing about 0.3-14µg**
- **The embryo of seeds contains 10-100 cells and there is virtually no storage of food**
- **The embryo is encircled in a thin-walled net-like testa that helps in their dispersal**
- **The majority of seeds are unable to germinate without exogenous supply of carbohydrates, the fungus provides C-nutrition to the seeds**

- **Therefore, mycorrhizal association is obligatory for the seeds to germinate**
- **Once the seed coat ruptures and roots begin to emerge, the hyphae of orchidaceous mycorrhiza penetrate the root's cells and create hyphal coils, or pelotons, which are sites of nutrient exchange**
- **Initially the fungus enters the embryo and colonises, being restricted to the cortical cells and provides the nutrition**
- **For non-green orchids, this is obligatory throughout their lives**
- **Apparently, it is a case of parasitism by orchids on the mycorrhizal fungi**
- **Fungi like Rhizoctonia (Basidiomycotina), are recognised by hyphal characteristics. Corticium, Ceratobasidium etc., of Aphylloporales are associated in this type of mycorrhiza**

Monotropoid mycorrhizae

- Monotropa hypopitys is a non-green saprophytic herb associated to grow with Pinus trees
- It has short fleshy roots that are invested with a hyphal sheath and often forming Hartig net in the cortical zone
- Due to absence of chlorophyll, they are unable to synthesise and supply carbohydrate to the fungus
- Boletus is a mycorrhizal fungus associated with roots of both pine and Monotropa
- The fungus Boletus acts as a bridge between Monotropa and Pine plants
- The experimental facts indicate a bidirectional flow of nutrients between the plants through the fungus Boletus

Examples of Association

Vesicular-Arbuscular (VA) mycorrhizas: Fungi: Glomalean (130 spp.), Plant: Gymnosperms, Angiosperms, Pterophtyes, Bryophytes, generally low host specificity

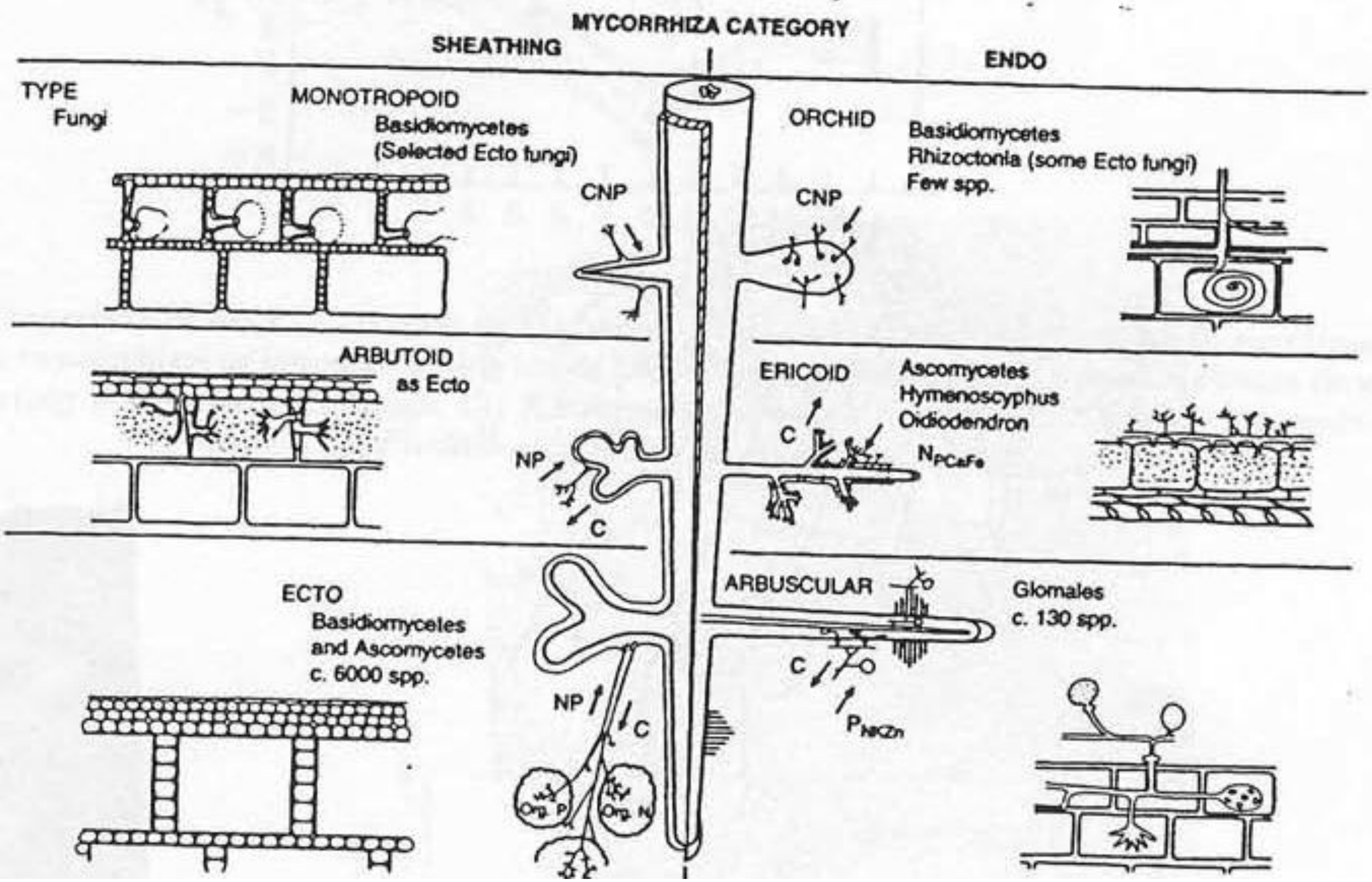
Ectomycorrhizas (ECM): Fungi: Basidiomycete and Ascomycete (6000 sp.), Plant: Gymnosperms and Angiosperms, low to moderate host specificity

Arbutoid mycorrhizas: Fungi: Basidiomycete, Plant: Ericales

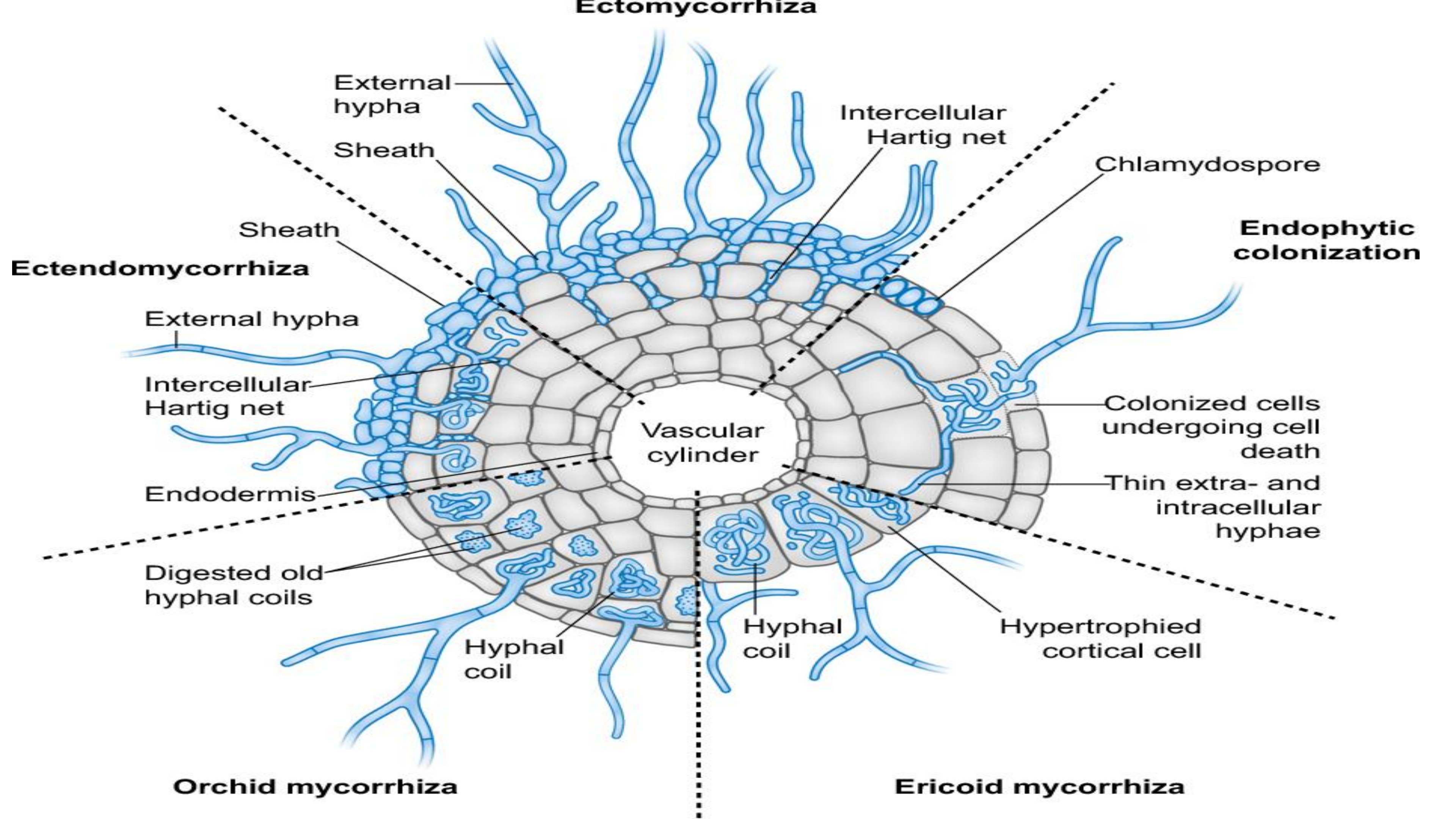
Ericoid mycorrhizas (ERM): Fungi: Ascomycete, Plant: Ericales and Byrophytes

Monotropoid mycorrhizas: Fungi: Basidiomycete, Plant: Monotropaceae (Ericales), high fungal specificity

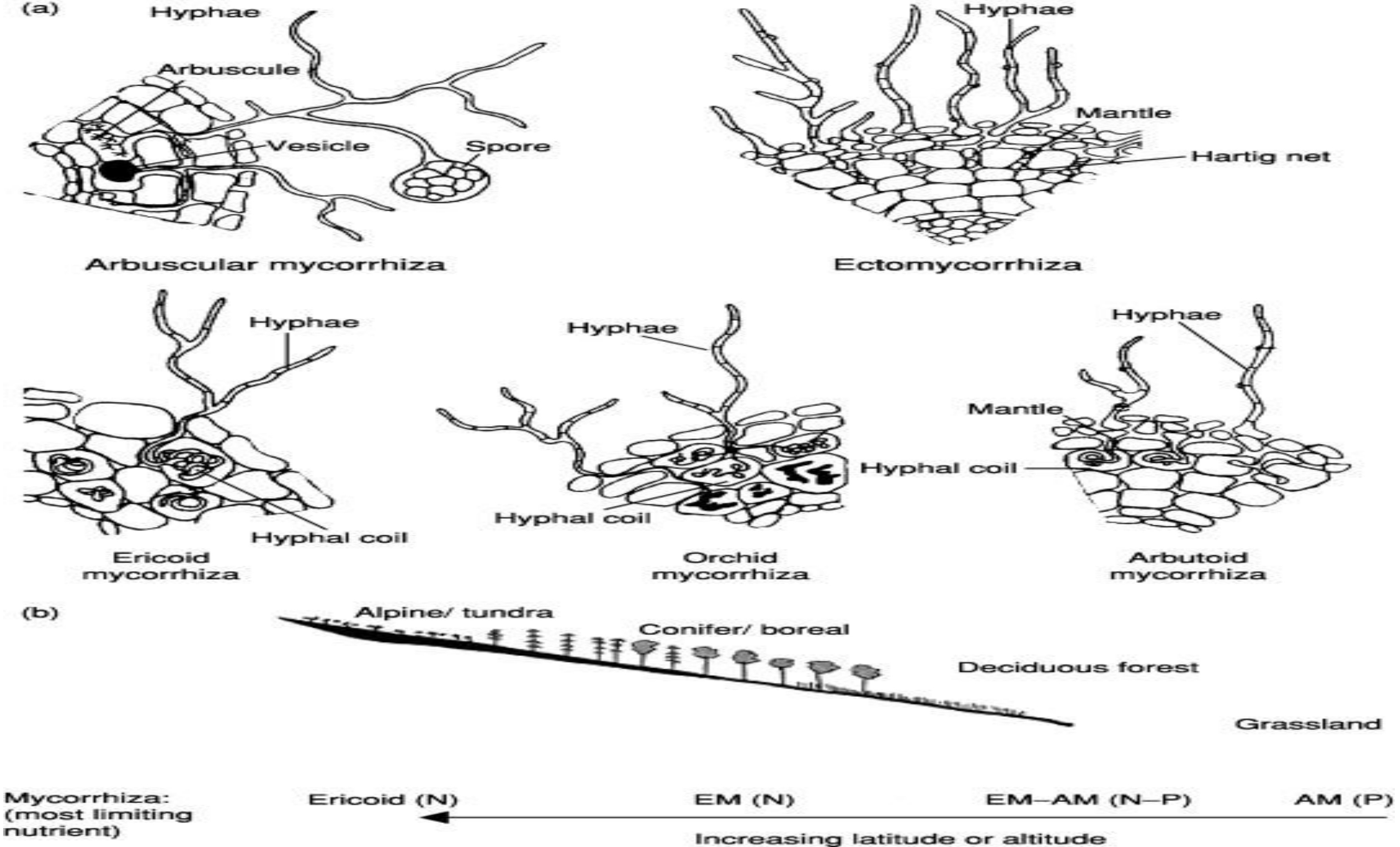
Orchid mycorrhizas: Fungi: Basidiomycete, Plant: Orchidaceae



MYCORRHIZA CATEGORY
SHEATHING
ENDO
TYPE
Fungi
MONOTROPOID
Basidiomycetes
(Selected Ecto fungi)
CNP
ORCHID
Basidiomycetes
Rhizoctonia (some Ecto fungi)
Few spp.
CNP
ARBUTOID
as Ecto
NP
C
ERICOID
Ascomycetes
Hymenoscyphus
Oidiodendron
C
N_{PCaFe}
ECTO
Basidiomycetes
and Ascomycetes
c. 6000 spp.
NP
C
Org. P
Org. N
ARBUSCULAR
Glomales
c. 130 spp.
C
P_{NKZn}



Ectomycorrhiza
External hypha
Sheath
Intercellular Hartig net
Chlamydospore
Endophytic colonization
Sheath
Ectendomycorrhiza
External hypha
Intercellular Hartig net
Vascular cylinder
Colonized cells undergoing cell death
Endodermis
Thin extra- and intracellular hyphae
Digested old hyphal coils
Hyphal coil
Hyphal coil
Hypertrophied cortical cell
Orchid mycorrhiza
Ericoid mycorrhiza


(a)
Hyphae
Arbuscule
Vesicle
Spore
Arbuscular mycorrhiza
Hyphae
Mantle
Hartig net
Ectomycorrhiza
Hyphae
Hyphal coil
Ericoid mycorrhiza
Hyphae
Hyphal coil
Orchid mycorrhiza
Hyphae
Mantle
Hyphal coil
Arbutoid mycorrhiza
(b)
Alpine/ tundra
Conifer/ boreal
Deciduous forest
Grassland
Mycorrhiza: (most limiting nutrient)
Ericoid (N)
EM (N)
EM–AM (N–P)
AM (P)
Increasing latitude or altitude

Mutualist dynamics

Nutrient exchanges and communication between a mycorrhizal fungus and plants

- In such a mutualistic relationship, both the plants themselves and those parts of the roots that host the fungi, are said to be mycorrhizal
- This relationship was noted when mycorrhizal fungi were unexpectedly found to be hoarding nitrogen from plant roots in times of nitrogen scarcity
- Researchers argue that some mycorrhizae distribute nutrients based upon the environment with surrounding plants and other mycorrhizae

- **The mechanisms by which mycorrhizae increase absorption include some that are physical and some that are chemical**
- **Physically, most mycorrhizal mycelia are much smaller in diameter than the smallest root or root hair, and thus can explore soil material that roots and root hairs cannot reach, and provide a larger surface area for absorption**
- **Chemically, the cell membrane chemistry of fungi differs from that of plants, they may secrete organic acids that dissolve or chelate many ions, or release them from minerals by ion exchange**

Sugar-water/mineral exchange

- The fungal hyphae increase the surface area of the root and uptake of key nutrients while the plant supplies the fungi with fixed carbon
- The carbohydrates are translocated from their source (usually leaves) to root tissue and on to the plant's fungal partners
- In return, the plant gains the benefits of the mycelium's higher absorptive capacity for water and mineral nutrients, partly because of the large surface area of fungal hyphae, which are much longer and finer than plant root hairs and partly because some such fungi can mobilize soil minerals unavailable to the plants' roots

- **In some more complex relationships, mycorrhizal fungi do not just collect immobilised soil nutrients, but connect individual plants together by mycorrhizal networks that transport water, carbon, and other nutrients directly from plant to plant through underground hyphal networks**
- ***Suillus tomentosus*, a basidiomycete fungus, produces specialized structures known as tuberculate ectomycorrhizae with its plant host lodgepole pine (*Pinus contorta* var. *latifolia*)**
- **These structures have been shown to host nitrogen fixing bacteria which contribute a significant amount of nitrogen and allow the pines to colonize nutrient-poor sites**

Disease, drought and salinity resistance and its correlation to mycorrhizae

- Mycorrhizal plants are often more resistant to diseases, such as those caused by microbial soil-borne pathogens
- These associations have been found to assist in plant defense both above and belowground
- Mycorrhizas have been found to excrete enzymes that are toxic to soil borne organisms such as nematodes
- More recent studies have shown that mycorrhizal associations result in a priming effect of plants that essentially acts as a primary immune response

- **When this association is formed a defense response is activated similarly to the response that occurs when the plant is under attack**
- **AMF was also significantly correlated with soil biological fertility variables such as soil microbial communities and associated disease suppressiveness**
- **The significance of arbuscular mycorrhizal fungi includes alleviation of salt stress and its beneficial effects on plant growth and productivity**
- **Although salinity can negatively affect arbuscular mycorrhizal fungi, many reports show improved growth and performance of mycorrhizal plants under salt stress conditions**

Resistance to insects

- Research has shown that plants connected by mycorrhizal fungi can use these underground connections to produce and receive warning signals
- When a host plant is attacked by an aphid, the plant signals surrounding connected plants of its condition
- The host plant releases volatile organic compounds (VOCs) that attract the insect's predators
- The plants connected by mycorrhizal fungi are also prompted to produce identical VOCs that protect the uninfected plants from being targeted by the insect

Colonization of barren soil

- Plants grown in sterile soils and growth media often perform poorly without the addition of spores or hyphae of mycorrhizal fungi to colonise the plant roots and aid in the uptake of soil mineral nutrients
- The absence of mycorrhizal fungi can also slow plant growth in early succession or on degraded landscapes
- The introduction of alien mycorrhizal plants to nutrient-deficient ecosystems puts indigenous non-mycorrhizal plants at a competitive disadvantage
- This aptitude to colonize barren soil is defined by the category Oligotroph

Resistance to toxicity

- **Fungi have been found to have a protective role for plants rooted in soils with high metal concentrations, such as acidic and contaminated soils**
- **Pine trees inoculated with *Pisolithus tinctorius* planted in several contaminated sites displayed high tolerance to the prevailing contaminant, survivorship and growth**
- **One study discovered the existence of *Suillus luteus* strains with varying tolerance of zinc**
- **Another study discovered that zinc-tolerant strains of *Suillus bovinus* conferred resistance to plants of *Pinus sylvestris***
- **This was probably due to binding of the metal to the extramatricial mycelium of the fungus, without affecting the exchange of beneficial substances**

Plant Benefits from Mycorrhizae

- **Nutrient absorption**
- **Resistance to soil born diseases**
- **Nutrient translocation from plant to plant**
- **Improvement of soil structure and quality**
- **Support Nitrogen uptake in association with bacteria**

Fungi Benefits from Plants

- Supply of photosynthesis products
- All of this is necessary for fungal growth and reproduction
- Surface area for growth and colonization