Almost all of us encounter fungi in our daily life, although some of us may not know much about them. The child is familiar with puffballs, mushrooms or toadstools growing outside, and housewife is familiar with them as these often grow in jams, jellies, pickles and bread. She may even use yeasts to leaven her bread. Farmers are familiar with fungi because they often cause diseases like rusts, smuts, mildews, blights and root rots and may spoil stored grains, fruits and vegetables, causing millions of dollars’ worth of spoilage. A layman and foresters are familiar with the large polypores that form bracket and shelf on trees, and the puffballs, toadstools and mushrooms that grow in gardens and forests. Urban people may not have seen fungi in their natural habitat but they may have suffered from fungal diseases such as ringworm, athlete’s foot, mycetoma, madura foot, cryptococcosis, histoplasmosis, candidiasis, aspergillosis or fungal allergies.

The Fungi and their allies include the chytrids, molds, yeasts, water molds, powdery mildews, mushrooms, bracket fungi, puffballs, morels, truffles, cup fungi, rusts, smuts, jelly fungi, dermatophytes, and many more for which there are no common names. The total variability of life on Earth is termed **biological diversity** or **biodiversity**. Biodiversity is not simply the total number of species; it encompasses the complexity, richness and abundance in nature at all levels from the genes carried by local populations to the layout of communities and ecosystems across the landscape. There are no accurate estimates of the total number of fungal species on a global or regional basis. The number of species so far discovered, however, is probably only a small proportion of those that exist, as few habitats and regions have been extensively studied. In well studied regions fungal species can be six times as numerous as those of flowering plants. On this basis, since about 270000 flowering plants are known, there may be about 1.6 million fungal species. Based on the 10th edition of the **Ainsworth and Bisby’s Dictionary of the Fungi**, there are one lakh named species of fungi. (Hawksworth, 1991; Singh and Aneja, 1999; Kirk et al., 2008; Subramanian, 2013).

Fungi are highly diverse and versatile organisms adapted to all kinds of environments. These are ubiquitous organisms found on earth, in water, in moist soil, in compost, or in decomposing organic matter as **saprobes** (or **saprophytes**) meaning that they obtain nutrients (organic materials) from the remnants of dead organisms. They release hydrolytic exoenzymes that digest external substrates and then absorb the soluble products. They are known as **chemoorganoheterotrophs** i.e. those that use organic compounds as a source of carbon, electron and energy. They are also present in bodies of living
plants and animals as parasites, or symbionts playing an essential role in the economy of nature. In general, a fungus colonizes a substrate and reduces it to small molecules that can be absorbed by the cells. Fungi have enzymes for degrading an incredible array of substrates, including feathers, hair, cellulose, petroleum products, wood and rubber. The beneficial activities of fungi include the production of antibiotics—penicillin, griseofulvin and antiamoebin, Roquefort and Camembert cheeses, soya sauce, riboflavin and various important drugs such as ergotamine and cortisone which are the products of fungal activity. Fungi are also used industrially in the manufacture of organic acids, enzymes, fats, steroid transformations, carcinogenic drugs and feed supplements. Ancient people were familiar with the biological fermentation of yeasts that is their use in bread making, production of alcohol and alcoholic beverages such as wine and beer. Yeasts have played an important role in the nutrition of the human race.

Fungi are important as parasites, but their impact on the rest of the biosphere is the most striking when they are playing their saprobic role. These have been decaying plant and animal bodies for the last two billion years and liberating various elements such as nitrogen, phosphorus, potassium, sulphur, iron, calcium, magnesium and zinc. These would forever be locked up in their bodies without the activity of fungi and bacteria, that liberate carbon dioxide into the atmosphere and used again in photosynthesis by green plants. Their complex and multiple enzyme systems enable them to function as scavengers in the destruction of cellulose, hemicellulose, lignin, pectin and various carbohydrates and nitrogenous substances which accumulate on the earth surface with the death of autotrophic plants and heterotrophic animals and insects. Their ability to break down complex organic substrates of every kind is an essential activity in the recycling of various elements in the cycle of life. Soil fertility is closely linked with fungal activity; the roots of most green plants are infected with fungi and absorption of minerals may be enhanced after infection. Such infected root systems are termed as mycorrhizae. The ability of higher plants to grow in infertile natural soils depends upon mycorrhizae. Thus fungi are among the most important organisms in the world, not only because of their vital roles in ecosystem functions but also because of their influence on humans and human related activities. Fungi are essential to such crucial activities as decomposition, nutrient cycling and nutrient transport and are indispensable for achieving sustainable development (Palm and Chapela, 1998).

One of the predominant interests of man in fungi is their use as food. Fungi collected for food include truffles, morels, mushrooms, puffballs, clavarias and non-woody polypores. Mushrooms, such as Agaricus brunneescens (syn. Agaricus bisporus), the white button mushroom, and others are now being cultivated commercially in the United States, Europe and the Orient (India, China and Japan) which is a billion dollar industry. The French have discovered a method of establishing “truffle farms” the industry will receive a new impetus, because truffles are considered to be the most exquisite of all fungi in flavour. Many cultivated and wild mushrooms and morels are edible (e.g., Agaricus campestris, Morchella esculenta) and have an excellent flavour, however, some of them are deadly poisonous (e.g., Amanita phalloides, the so-called death cap). It is, therefore, important that unless their identity is known, mushrooms from fields should not be consumed.

A few mushrooms such as Psilocybe mexicana produce an euphoric, dream like state when eaten. For centuries, some mushrooms were used in religious ceremonies by many ancient civilizations and primitive tribes, who collected and consumed these that contained hallucinogenic chemicals. The well-known hallucinogen LSD (d-lysergic acid diethylamide) is synthesized from lysergic acid, which occurs in ergot sclerotia of Claviceps purpurea.

Fungi also cause the destruction of wood, textiles, leather goods, electrical insulation and blur the lenses of cameras, binoculars, telescopes, and other optical instruments in humid climates. Apart from these applied aspects of fungi, physiologists, microbiologists, biochemists, cytologists and
geneticists often find them ideally suited as tools for the study of the fundamental biological processes. They are also useful test organisms for the bioassay of various chemicals and trace elements.

As a group, fungi have what it takes to survive. Fungi are progressive and evolve rapidly so they are capable of rapidly adapting to every condition of life. Fungi were around long before man appeared, and many of them are sure to be around in the future.

The scientific discipline dealing with fungi is called mycology, and the scientists who study fungi are known as mycologists. The study of fungal toxins and their effects on various organisms is known as mycotoxicology, and the diseases caused in animals (including humans) are called mycoses (sing. mycosis).

**Definition**

To give a precise definition of a fungus is difficult as fungi vary in forms, behaviour and life-cycles. Alexopoulos and Mims (1979) defined fungi as “eukaryotic, spore-bearing, achlorophyllous organisms that generally reproduce sexually and asexually and whose usually filamentous, branched somatic structures are typically surrounded by cell walls containing chitin or cellulose, or both of these substances, together with many other complex organic molecules.” Fungi are chemoheterophic organisms that derive both carbon and energy from organic compounds that originate from autotrophs and other heterotrophs.

This definition of fungi now needs modification. Recent studies indicate that members of kingdom Fungi are most closely related to animals not plants, possibly through a choanoflagellate like ancestor. Based on data presently available, Blackwell and Spatafora (2004) reported that the organisms studied by mycologist are polyphyletic (i.e., developed from more than one ancestral type) and belong to two different kingdoms (i) kingdom Fungi that includes true fungi (e.g., Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota); (ii) kingdom Straminipila (Oomycota, Hypochytriomycota, Labyrinthulales, and Thraustochytriales) and a clade slime molds (Plasmodiophorales, Myxomycota, Dictyosteliomycota, and Acrasiomycota). Thus, the members of Straminipila and slime molds are, not fungi but considered as fungus-like organisms. The slime molds are placed in the kingdom Protozoa in the 9th edition of the Dictionary of the Fungi (Kirk et al., 2001). The fungi and fungus-like organisms are eukaryotic and heterotrophic enveloped by cell walls and reproduce both sexually and asexually by spores. Currently true fungi are defined as eukaryotic organisms lacking plastids, with absorptive nutrition, reproducing both sexually and asexually by spores and hyphae surrounded by cell walls containing chitin and β-glucans, and mitochondria with flattened cristae and peroxisomes.

**Thallus Organisation**

Some fungi are unicellular, but the majority have a differentiated thallus consisting of threadlike, tubular filaments, the hyphae (sing. hypha, Gr. hyphe = web). In most fungi, the thallus is differentiated into a vegetative part which absorbs nutrients, and a reproductive part which forms reproductive structures. Such thalli are called eucarpic (Gr. eu = good + karpos = fruit). In some, however, the thallus does not show this differentiation and after a phase of vegetative growth, changes into one or more reproductive structures. Such thalli are called holocarpic (Gr. holos = entirely + karpos = fruit). The network of hyphae constituting the body (thallus, soma) of a fungus is called a mycelium (Gr. mykes = mushroom, fungus). A hypha is made up of a thin transparent, tubular filament, filled with a layer of cytoplasm varying in thickness. In the simpler filamentous fungi, septa are always formed at the base of reproductive
organisms and the vigorously growing hyphae are coenocytic (Gr. koinos = common + kytos = a hollow vessel) which means they are nonseptate or aseptate with nuclei in a common matrix (Fig. 1.1). Paul Vuillemin in the year 1912 used the term coenocyte (adj. coenocytic) for a cell usually multinucleate and apocyte for one temporarily or secondarily multinucleate. When the mycelium contains genetically identical nuclei, it is called homokaryotic (Gr. homo = the same + karyon = nucleus), and when it contains two or more genetically different nuclei, the mycelium is said to be heterokaryotic (Gr. heteros = other + karyon = nucleus). In the more complex groups, the hyphae are divided into compartments or cells by cross walls called septa (Fig. 1.1): primary and adventitious. The primary septa are formed during nuclear divisions and are laid down between daughter nuclei. The adventitious septa are formed independently of nuclear division and are especially associated with changes in the concentration of the protoplasm as it moves from one part of the hypha to another.

![Fig. 1.1. Two types of somatic hyphae: coenocytic (nonseptate) and septate.](image)

The hyphae in ascomycetes, basidiomycetes and anamorphic fungi are regularly septate (Fig. 1.1). In some species septa occur close together, in others they are widely separated. In contrast to those of lower fungi, the septa of other groups are incomplete, and have a minute central pore through which protoplasmic continuity is maintained throughout the length of the hypha (Fig. 1.2). It means the hyphae are not divided into a series of independent cells, but are coenocytic with incomplete septa. Thus difference between coenocytic and septate fungi is not so profound as had been imagined (Burnett, 1976). Septa are perhaps thought to be one of the strengthening features of the hyphae.

Electron microscope studies of the septum in fungi indicate that in the ascomycetes and Uredinales examined it is a simple poroid disc (Fig. 1.2) whereas in other basidiomycetous fungi a complex type of septum is present. In this septum a central pore surrounded by a barrel-shaped swelling of the septal wall is produced. Moore and McAlear (1962) have termed it as the dolipore septum (L. dolium = a large jar or cask, i.e., barrel) (Fig. 1.2). The dome shaped, membranous structure covering the dolipore septum on either side, is variously referred to as the Verschlussband, the parenthesome or the septal pore cap. The septal pore cap which has several pores, is endoplasmic reticulum and, is an integral and functional part of the septal apparatus. The septum arises by the centripetal growth of a cross wall from the lateral wall of the hypha. The septal pore swellings are formed on the perimeter of the pore from a
material which seems to be of a different composition from that of the cross wall. Several functions have been attributed to the dolipore septum but its exact function remains unclear. It would seem, however, that the pore cap acts as a screen or sieve, possibly permitting the passage of some cellular structures from one cell to the next while retarding others. A breakdown of the septal apparatus has been reported during nuclear migrations associated with the dikaryotization in *Coprinus lagopus*, a basidiomycetous fungus.

In a strict sense, a cell contains only a single nucleus and the term *coenocytic* would describe more accurately a compartment with more than one nucleus. Regardless of the number of nuclei present in a cell, hyphal segments between septa are usually termed as cells. The individual cells of septate hyphae may contain one, two or many nuclei. The hyphal diameter may range from 1-2 µm to 25 µm or more. In a few groups, the hyphae taper towards the tip. This happens in the *Saprolegniaceae*. In *Achlya conspicua* the hyphae are broad at the base and measure 160–170 µm.

**Rhizomorphs**

In many root invading or wood destroying fungi, hyphae are aggregated longitudinally in varying degrees of complexity in such a way that the hyphae lose their individuality and form complex tissues that form the organs of mycelial migration and food transport. Such a tissue is known as a *rhizomorph* (Gr. *rhiza*
Loosely woven hyphae  Closely packed oval cells  Reproductive body  Stromatic body

Fig. 1.3. Hyphal modification to form fungal tissues (A, B) and somatic structures (C-E).  
(A) Prosenchyma. (B) Pseudoparenchyma. (C) Stroma of Daldinia in section. (D-E) Sclerotium of Claviceps purpurea. (D) A sclerotium. (E) Cross-section of sclerotium.

= root +  = shape) because of the resemblance of its tip to that of a root tip. The rhizomorph best studied is that of Armillaria mellea. It is made up of several thousand unbranched parallel hyphae which grow in a co-ordinated manner (five to six) times faster than normal hyphae. The apex of the rhizomorph consists of interwoven hyphae which become denser at its core and are enclosed in a mantle of loose hyphae, about 5 mm to 10 mm behind the apex. The fringing mantle makes a rhizomorph look-like a root covered in root hairs and an analogous function may well be performed by it. Garrett (1956, 1963) reported that compared to individual hyphae, the significance of mycelial aggregation lies in the pooling of resources of many hyphae which provides a great inoculum potential to the invading hyphae in either colonization of a dead substrate or infection of a host.

**Appressoria**

The hyphae of many plant pathogenic fungi, for example in certain Uredinales and species of Colletotrichum, Glomerella develop special structures for attachment to the host in the early stages of infection; these are called appressoria (sing. appressorium; L. apprimere = to press against). Appressoria are localized swellings of the tips of germ tubes or hyphae that develop in response to contact with the host from which minute infection peg usually grows and penetrates the epidermal cell of the host.

**Haustoria**

Most biotrophs and some facultative parasites possess haustoria that are lateral outgrowths of intercellular hyphae (or superficial hyphae in powdery mildews) specially modified for absorption of nutrients. Haustoria are of various shapes and sizes ranging from knob like structures, to simple, lobed, branched, coiled or coralloid hyphae (Fig. 1.4). They may be small and rather insignificant or extensive and almost fill the host cell. Haustoria penetrate the cell wall but do not rupture the plasma membrane even though they ramify extensively. These organs vary greatly in gross and fine structural anatomy depending upon the parasite in question.
Fig. 1.4. Types of haustoria: (A) of Coleosporium senecionis in cell of groundsel; (B) of Peronospora parasitica in leaf cell of wallflower; (C) of Peronospora calotheca in stem cells of Asperula odorata; (D) of Erysiphe polygoni in epidermal cell of garden pea; (E, F) of Blumeria (= Erysiphe) graminis in epidermal cell of oat, in longitudinal section (E) and surface view (F); (G) of Puccinia triticina in mesophyll cell of little club wheat. i = intercellular hyphae; n = narrow neck; t = thickening of host wall (Redrawn from S.A.J. Tarr, 1972).

The wall of the haustorium is generally continuous (Fig. 1.5A), but an apparent exception is noted in Albugo (Fig. 1.5B). At the point of entry of haustorium, a sheath develops that is apparently an ingrowth of the host cell wall (Fig. 1.5A and B). A relatively dense layer envelopes the whole haustorium and it becomes thicker in the region between the haustorial wall and sheath. This layer is termed "zone of apposition". Several features commonly associated with the haustoria may be seen in the ultrastructure micrograph of Melampsora lini. Intracellular hyphae of certain smut fungi have been found to be completely ensheathed in hostwall—like material. The ensheathing process appears to be similar to normal cell wall formation.
Fig. 1.5. Diagrams of host-parasite relationship in haustorial region. (A) *Peronospora manshurica* infection of soybean (*Glycine max*). (B) *Albugo candida* infection of radish (*Raphanus sativus*) leaf. Host mesophyll cells are on the left and intercellular hyphae on the right. FC = fungal cytoplasm; FP = plasma membrane; LO = lomasomes; FW = fungal cell wall; V = vacuole; HC = host cell wall; S = sheath; A = zone of apposition; sac = host secretory activity (Redrawn from Moore, 1965).

Vesicles have been observed in the region of the host plasma membrane that bounds the haustorium and some were noted to be continuous with it as in *Peronospora* and *Puccinia*. According to Peyton and Bowen (1963), these vesicles are derived from the host cytoplasm and fuse with the plasma membrane to release material into the zone of apposition thus transferring food through the host cytoplasm via the zone of apposition to the fungus. This also takes place in *Albugo* (Fig. 1.5). Ehrlich and Ehrlich (1963), however, believe that vesicles are pinched off the plasma membrane and carry material from the ‘encapsulation’ (zone of apposition) into the host cytoplasm.

The haustorial sheath plays an essential role in transfer of nutrients between host and parasite. For example, in *B. graminis* large amounts of S-35 or P-32 are transferred from host to fungus 16 hours after inoculation. At this time, the primary haustorium is established and beginning to branch. It is known that carbohydrates are also transferred from host to parasite. But the role of the haustorium in this exchange is not clear. There is every possibility that they may transfer toxins, enzymes or possible hormones from fungus to the host or that in some way, the fungus might regulate the host enzyme and metabolic systems to produce them.

**Traps**

Traps are modifications of hyphae in predacious fungi for the capture of small animals, protozoa, rotifers and nematodes. Some of these fungi belong to *Zygomycetes* (*Zoopagales*), but the majority of them are Fungi-Imperfecti. There are mainly two types of predacious activity; capture by adhesion, and capture by mechanical traps. The fungi which capture their prey by adhesion possess no special modification of structure, and rely on the production of a sticky substance in which the victims are held *e.g.*, *Stylopage grandis*, species of *Harposporium*, *Mertia* and *Nematoctonus*. **Lateral adhesive branches** are formed in other genera including *Dactylella*, *Sommerstorffia spinosa* and *Zoophagus insidians*.

The most common trap among eelworm catching hyphomycetes is the **adhesive network** found in *Arthrobotrys oligospora*. This arises by the formation of short lateral branches that curve around and anastomose with the parent hyphae or with neighbouring branches, forming a complex three dimensional
network in which eelworms become entangled and are held by the sticky secretion produced by the cells of the loops.

**Mechanical traps** are formed in *Dactylaria candida* and *D. gracilis*. A mechanical trap consists of a constricting ring where cells borne on a lateral branch swell to about three times of its original volume on coming in contact with the prey, and hold the animal until hyphal branches invade and digest it.

**Dimorphism**

Some fungi especially human and animal pathogens, can exist either in yeast form or in mycelial form and are said to be **dimorphic**. This phenomenon is termed as **dimorphism**. Common examples of human fungal pathogens showing dimorphism are *Histoplasma*, *Sporothrix* and *Blastomyces*. In infected tissues dimorphic fungi occur as single yeast-like cells that multiply by budding but become mycelial in their saprophytic growth in culture as in *Blastomyces* (*Ajellomyces*) *dermatitidis* (Fig.1.6) causing blastomycosis in humans. The dimorphism appears to be an inherent characteristic of a number of fungi. This phenomenon has also been observed in members of *Taphrinales* and *Ustilaginales*, which are mycelial in their plant hosts but yeast like in artificial culture.

In the dimorphic fungi, a number of different factors influence the conversion between morphological forms. In some cases a rise in temperature at which cells are grown will cause the switch in growth form e.g., from 20–25°C to 37°C causes yeast like growth in *Paracoccidioides brasiliensis* and *Blastomyces dermatitidis*. The main effect of this is an alteration in the composition of cell walls. Dimorphism in *Candida albicans* is influenced by factors other than temperature changes. In this case the morphological switch has been attributed to changes in the chemical bonds within the cell wall structure, which are brought about by differences in carbon metabolism and effected in culture by different nutrient substances. In other species, such as *Mucor*, it is the degree of aeration and the supply

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**Fig. 1.6.** *Blastomyces dermatitidis*, a dimorphic fungus. (A) Short conidiogenous cells bearing aleuriospores. (B) Bud cells produced in host tissue. (C) Budding cells on culture medium at 37°C.
of CO₂, which influence the conversion between yeast and mycelial phases. It has also been shown that a relationship exists between the concentration of AMP in *Mucor rouxii* and cell morphology.

**Cell Structure**

The cell structure of prokaryotes is simpler than that of eukaryotes. Cells of bacteria lack mitochondria, plastids, nuclear membranes, mitotic spindles, endoplasmic reticulum, Golgi apparatus, vacuoles, and advanced (9 + 2 strands) flagellar structure. These organelles are characteristic of the cells of plants, animals, and many other organisms such as algae (except blue green), fungi, protozoa and slime molds. Fungal cells are typically eukaryotic and lack chloroplasts (Fig. 1.7). Recent studies indicate that the true fungi are most closely related to animals, not plants. Fungi are usually filamentous and multicellular; their nuclei, although small, can be demonstrated with relative ease; and their primary carbohydrate storage product is glycogen.

![Diagram of fungal cell structure](image)

*Fig. 1.7. Diagrammatic representation of the ultrastructure of a cross-section of a typical fungal cell.*

**Cell Membrane**

In fungal cells, as in other eukaryotic cells, the living protoplast is enclosed in a cell membrane, the plasma membrane or plasmalemma. It is a tripartite structure composed of two electron dense regions separated by a transparent region. Each layer measures approximately 25–30Å. This tripartite structure which occurs in many biological membranes is termed as “unit membrane”. The plasmalemma is usually adpressed to the cell wall, but may become undulating or invaginated during certain developmental stages of some organisms or certain conditions. The principal components of the plasmalemma are protein and lipids. Glucosamine and glucose residues account for most of the carbohydrate, but appreciable amounts of mannose are also present.

**Organelles**

The cytoplasm of fungal hyphae resembles that of other eukaryotic cell in the presence of such organelles as nucleus, mitochondria, microbodies, Golgi bodies, ribosomes, vacuoles, vesicles, endoplasmic...