Textbook of Fungi

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Preface

A general survey of fungal literature of the past two decades reveals the enormous increase in our knowledge of this group of biologically fascinating organisms. Their morphological diversity, their importance as main decomposers, their utility in genetic experiments as well as in the field of medicine, and their direct involvement in causing thousands of diseases among men, animals and plants, have made their study essential for laymen as well as specialists. *Textbook of Fungi* is my attempt to provide a comprehensive book on fungi for undergraduate students.

A straightforward question may be asked—why a new book on fungi when several books written by Indian authors are already available in the market? To justify the need for a new book, I would like to mention that none of these deal with the entire subject matter in the light of recent developments unveiled by electron microscopy and other new techniques. After preparing a basic outline of the manuscript, I consulted the *Biological Abstracts* from 1965 to November 1987 and collected over 1500 references. Out of these, 817 references which related to the topics discussed in this book, were finally selected. The manuscript was finalized on the basis of these 817 references, and these have been listed in the Bibliography at the end of the book. Treatment of the subject in the light of available information up to 1987 has made the text completely up-to-date, as was actually my main aim in writing this book. Moreover, I also felt the need to write a book tailored to suit the requirements of Indian universities.

In most Indian universities, the phyletic approach to the teaching of fungi is still followed—various fungal divisions are individually presented and discussed along with the detailed life-history of some representative genera. I have followed the same approach in this book. Besides presenting a general account of all major divisions of fungi proposed by Ainsworth (1973), the detailed life-history of over 40 representative genera are given, mainly to suit the need of the syllabi of Indian universities. Classification of fungi and their economic importance is discussed in detail. Some rare groups such as Loculoascomycetes and Laboulbeniomycetes are also discussed. Although I found it necessary to introduce some physiological, ecological, genetic and biochemical data in a few places, I have kept it to a minimum to allow the book to remain an introductory text. Except for some casual remarks at a few places, I have kept the phylogeny of fungi out of this book.

Lichens, bacteria and viruses have also been discussed in this book. But this does not mean that I regard them as fungi since they are certainly not fungi. Lichens, of course, have a close affinity with fungi, but bacteriology and virology are absolutely separate scientific disciplines. They have been discussed in this book only because they are a part of the undergraduate courses of fungi in most Indian universities.

I shall be grateful and happy if readers like the book and find parts of the book useful for them. I would welcome constructive suggestions from all readers for further improvement.

O P Sharma

Acknowledgements

In writing this book I have drawn from various published articles and books on fungi in India and abroad. I wish to acknowledge my deeply felt gratitude to the authors of various scientific publications which form the basis of this book.

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1

Introduction

1.1 WHAT ARE FUNGI?

Fungi (L. *fungus*, mushroom) are achlorophyllous, heterotrophic (saprophytic, parasitic, symbiotic or hyperparasitic), eukaryotic and spore-bearing organisms surrounded by a well defined cell wall made up of chitin, with or without fungal cellulose, along with many other complex organic molecules. Fungi usually obtain food by absorption, except a few lower groups where they take in food by ingestion.

The study of fungi is also called *mycology* (Gr. *mykes*, mushroom or fungus; *logos*, discourse). According to Alexopoulos and Mims (1979), the Italian botanist Pier'Antonio Micheli(1729) deserves the honour of being called the 'founder of mycology' because of his researches on fungi which he published in *Nova Plantarum Genera*. Elias Fries (1794-1874), for his deep mycological understanding in earlier times, has been named the 'Linnaeus of Mycology' by Professor Eriksson Gunnar (1978) of Sweden.

1.2 NUMERICAL ESTIMATES OF FUNGI

According to the latest available estimates of Eizabeth Tootill (1984)published in *The Penguin Dictionary of Botany*, the fungi contain about 5100 genera and about 50,000 recognized species. 'However it has been estimated that the actual number of species may be between 100,000 and 250,000' (Tootill,1984). Ingold (1967) mentioned that 'the fungal kingdom is a large one with from 50,000 to 100,000 known species.'

1.3 WHY SHOULD WE STUDY FUNGI?

The study of fungi is important[1] for common man as well as for experts (Gray, 1959; Christensen,1965). Fungal saprophytes, along with bacteria, decay the complex plant and animal materials into simple form which is absorbed easily by the green plants. In the absence of this decaying process the future generations of green plants would not be able to survive for too long (Burges,1958). A good symbiotic relationship exists between the majority of green plants and fungi (Webster, 1980), because the latter infect the roots of the former under the mycorrhizal system. Food, timber and textiles, the three basic needs of human-being, are rotted by the fungi, making their study essential for us. Thousands of the diseases of plants (Brooks, 1953; Mehrotra, 1980) and animals (Ainsworth and Austwick,1973) are caused by the parasitic fungi. On the contrary, the fungi are needed as essential items in brewing and baking industries, cheese making, wine making, preparation of many acids and in the production of

[1] For details of economic importance of fungi, see Chapter 3.

antibiotics as well as many other drugs (Prescott and Dunn,1959; Rose, 1961). Yeasts are the sources of vitamins of B-complex group (Hawker, 1966). Further, many fungi are used as basic tools in scientific investigations of physiology (Cochrane, 1958), genetics (Fincham and Day, 1971; Burnett,1975), microbiology and biochemistry. Uses of *Neurospora* in genetical experiments, *Gibberella fujikuroi* in the discovery of gibberellins and yeasts in our knowledge of respiration process are well-known even to young students of biology.

1.4 HYPHA AND MYCELIUM

The fungi reproduce by means of one or more types of fungal *spores*. On being detached the spores are readily dispersed by wind and germinate on a suitable substratum by means of one or more tube-like outgrowths, called *germ tubes* (Fig. 1.1). Each germ tube elongates to form long, fine, branched filaments, called *hyphae* (Fig. 1.1). Each hypha (Gr.*hyphe*, web) divides by transverse walls or septa (L. *septum*, partition) and results into the formation of uninucleate or multinucleate cells. Such hyphae are called septate (Fig. 1.2A). Hyphae in many fungi do not develop the cross walls or septa, as in Phycomycetes. Such hyphae are called non-septate (Fig. 1.2B). Many nuclei are also present in such hyphae. The unicellular and multinucleate condition of the hyphae is called coenocytic (Gr.*koinos*, common; *koitos*, couch).

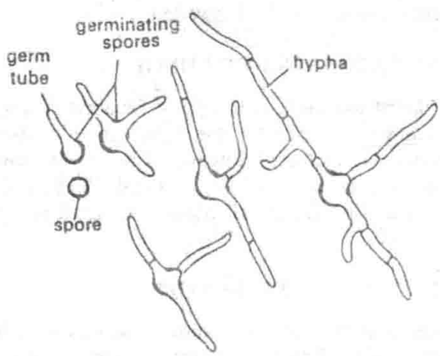

Fig. 1.1 Different stages of a germinating fungal spore

A mass of more or less loosely interwoven hyphae, constituting the vegetative body of most of the true fungi, is called *mycelium* (Gr. *mykes*, mushroom or fungus). The mycelium, if growing in between the host cells, is called intercellular. But if it penetrates into the cells it is called intracellular. The mycelial portion remaining inside the substrate is called vegetative mycelium, whereas the part that extends into the air and is responsible for spore production is called reproductive mycelium.

In many Basidiomycetes a small hyphal outgrowth develops into a short branch just behind the septum. This outgrowth becomes curved and its tip comes in contact with the cell on the other side of the septum. This all develops a communication link between the cell contents of two adjacent cells, leaving a characteristic clamp, called *clamp connection*.

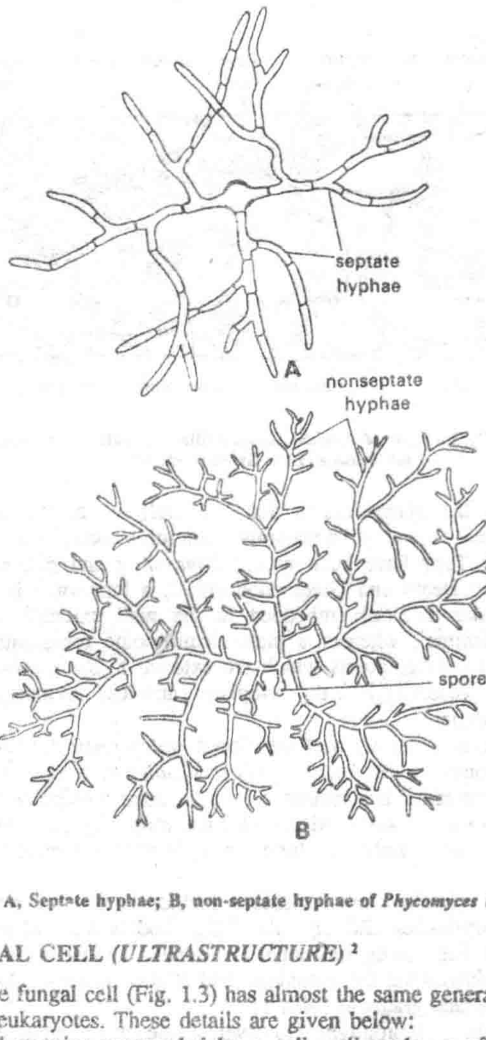

Fig. 1.2 A, Septate hyphae; B, non-septate hyphae of *Phycomyces blakesleeanus*

1.5 A FUNGAL CELL *(ULTRASTRUCTURE)* [2]

The vegetative fungal cell (Fig. 1.3) has almost the same general ultrastructure as that of other eukaryotes. These details are given below:

1. The cell remains surrounded by a *cell wall* made up of elongated microfibrillar units, which consist of chitin or fungal cellulose. Chitin, a cell-wall constituent of most fungi, was said to be absent in Oomycetes. But findings of Lin and Aronson (1970) and Lin *et al.* (1976) indicate its presence even in Oomycetes. According to Bracker *et al.* (1976) the chitin microfibrils are formed by the enzyme chitin synthetase.
2. The cell wall is followed by *plasmalemma*. It regulates the movement of soluble substances into and out of a hypha.

[2] For details, *see* Bracker (1967) and Beckett *et al.* (1974).

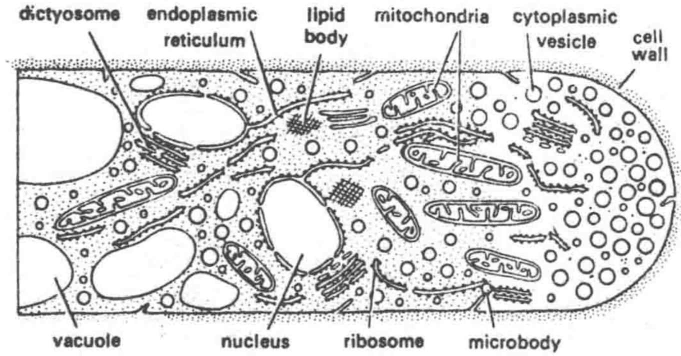

Fig. 1.3 Hyphal apex of *Pythium ultimum* (diagrammatic) as viewed under electron microscope (after Grove *et al.*, 1970)

3. In between the plasmalemma and cell wall, or at the surface of the plasmalemma, some membranous structures have been reported in some fungi. They have been named *lomasomes* and *plasmalemmasomes.* According to Heath and Greenwood (1970) a lomasome is the 'membranous vesicular material embedded in the wall external to the line of the plasmalemma', whereas a plasmalemmasome represents the 'various membranous configurations which are external to the plasmalemma, often in a pocket projecting into the cytoplasm, and less obviously embedded in the wall material'.
4. The cytoplasm contains a well-developed *endoplasmic reticulum.*
5. The cells contain either many smaller *vacuoles* or a single large vacuole, each of which remains surrounded by a vacuolar membrane or *tonoplast.*
6. *Mitochondria* and many food particles made up of glycogen and lipids are also present. Structurally the fungal mitochondria resemble those of green plants.
7. Other cell organelles and inclusions include ribosomes, vesicles, microtubules, microbodies and crystals. Golgi bodies are not reported in all fungal cells. Ribosomes are numerous, minute, almost of uniform size and distributed throughout the cytoplasm and also on endoplasmic reticulum.
8. Plastids or strach grains are absent.
9. All fungi lack chlorophyll. However, some other pigments have been reported to be distributed either in the cell wall, or irregularly in the cytoplasm, or just near the oil grobules. Matsueda *et al.* (1978) isolated a novel fungal pigment, neocercosporin (C_{29} $H_{26}O_{10}$, m.p.237° C) from *Cercosporina kikuchii*. It is a reddish violet pigment.
10. The cells are uninucleate or multinucleate, and the *nuclei* are either globose or ellipsoid. The nuclear membrane is porous and consists of an outer and an inner layer of electron-dense material and a middle layer of electron-transparent substance.
11. A well-developed nucleolus, consisting mostly of RNA, and distinct chromatin strands, which become organized into chromosomes during

nuclear division, are also present in the nucleus. The genetic information of the fungus is contained in the DNA of the chromosomes. Instructions are sent out into the cytoplasm by the messenger RNA, specially for the synthesis of enzymes and other proteins by the ribosomes.

12. The unit membrane of all the membrane-bound structures (like mitochondria, nucleus etc.) consists of phospholipids along with proteins. The membranes are of uniform thickness, of about 0.02 µ.

1.6 GROWTH

Most fungi do not require light for their vegetative growth. How. . ., it is needed by many species for sporulation and spore dispersal (Buller,1950). The optimum, minimum and maximum temperatures for growth vary from species to species but in most fungi the minimum is 2-5°C, the optimum 22-27° C, and the maximum 35-40° C. However, few species may survive at 0° C, and a few thermophilic species may endure a temperature of 60° C. Fungi generally require an acidic medium for normal growth, with a pH of approximately 6. The optimum pH for the growth of most of the fungi is 5-6.5, although a few fungi grow much below pH 3 and a few others even above pH 9 (Ingold,1967).

Oxygen supply is also an important factor for fungal growth. A majority of the fungi are aerobic and stop growing in the absence of oxygen. Like all other living organisms, water is an essential requirement for all fungi.

Regarding the longevity in fungi, Alexopoulos and Mims (1979) have mentioned that fungal colonies are known to grow continuously for 400 years or more if favourable conditions are available.

1.7 HAUSTORIUM

In many parasitic fungi(e.g.*Melampsora lini* and *Albugo candida*) the lateral branches of hyphae penetrate into the host cells and enlarge in the form of knob-like,elongated or branched absorptive organs called *haustoria* (L.*haustor*, drinker). The haustoria originate commonly on the hyphae of obligate parasites. However, they are also produced on the hyphae of some facultative parasites

Haustoria obtain nourishment from the protoplasts of the host cells. Electron microscopic studies of Coffey *et al.* (1972) and Coffey (1975) suggest that a penetrating fungal haustorium does not puncture the plasmamembrane of the host. It simply invaginates into it. Moreover, the fungal wall around the haustorium also remains intact and unruptured. A haustorium, therefore, mainly functions as an organ of increasing the absorptive area of the fungus.

1.8 NUTRITION

Fungi lack the green pigment, chlorophyll,and therefore remain unable to manufacture their own food material. The majority of the known fungi obtain food either from living organisms as *parasites* or from dead organic substances as *saprophytes*. Parasitic as well as saprophytic fungi may be either *obligate* or *facultative*. The living organism (either plant or animal) infected by a parasite is called a host. Besides the parasitic or saprophytic nature of fungi, many of them also remain in symbiotic relationship in the form of lichens or mycorrhyzae.

Alexopoulos and Mims (1979) mentioned that probably all fungi require C, O, H, N, P, K, Mg, S, B, Mn, Cu, Zn, Fe, Mo and also Ca in the form of essential elements to fulfil their nutritional requirements. Glucose, nitrogenous and ammonium compounds and nitrates form the best food for many fungi. Some compounds, functioning as vitamins, are also synthesized by them. Excess food is stored in the form of glycogen or lipids.

Food molecules of smaller size, specially in the form of solution, are easily absorbed by the fungi. But larger-sized food molecules are first broken into smaller-sized molecules by some extracellular enzymes, secreted by the fungus, and then absorbed.

1.9 REPRODUCTION

Fungi reproduce asexually as well as sexually. In the *asexual reproduction* certain types of spores are formed without involving the fusion of nuclei or sex cells. But in *sexual reproduction* formation and fusion of two types of sex cells or gametes take place. Some prefer to recognize a third category of reproduction in which certain part of the vegetative plant body separates and develops into the new individual of the same species. This category is called *vegetative reproduction*. However, none of the categories of vegetative reproduction involves the fusion of sex cells or gametes.

On the basis of the involvement of the entire thallus or a part of the thallus in the formation of reproductive organs, all fungi may be grouped into following two categories:

1. *Holocarpic fungi:* In genera such as *Synchytrium* the entire thallus converts into one or more reproductive bodies. Therefore, the vegetative and reproductive phases do not occur together. Such fungi are called holocarpic.
2. *Eucarpic fungi:* In majority of the fungi, only a part of the thallus develops into the reproductive organs, and the remaining part of the thallus continues to function its normal somatic activities. Such fungi are called eucarpic.

1.9.1 Asexual Reproduction

Alexopoulos and Mims (1979) put the asexual reproduction in fungi into four categories:

A. *Fragmentation:* In this method a part or fragment of the vegetative plant body detaches and develops into a new individual, as in a majority of the filamentous fungi.

B. *Fission:* It is a process in which splitting of the somatic cell results into the formation of two cells, as in yeast.

C. *Budding:* In this method a small outgrowth or bud is produced from the parent cell. The young bud later on separates from the parent cell and behaves as a new individual, as in *Saccharomyces*.

D. *Spore formation:* Various kinds of spores form the most common means of reproduction in a majority of fungi. The spores vary in shape (oval, globose, helical, oblong, needle-like), size (from very minute to large), colour (orange, yellow, brown, red, black or even transparent or hyaline), number (from one to many thousands in a spore-containing body), arrangement as well as in the way of their formation in different fungi. The structure responsible for spore production is called *sporophore*.

Some of the asexual spores are briefly described in the forthcoming account:

a. *Zoospore:* In many fungi the terminal end of the sporophore develops into a sac-like structure, called sporangium. The sporangium-bearing sporophore is called sporangiophore. The sporangiophore extends into the sporangium in the form of a sterile inflated end, called columella (Fig. 1.4A). The motile flagella-bearing spores are called *zoospores* and the sporangium containing them is called zoosporangium (Fig. 1.4B). On the contrary, non-motile, aflagellated zoospores are called *aplanospores* or *sporangiospores*

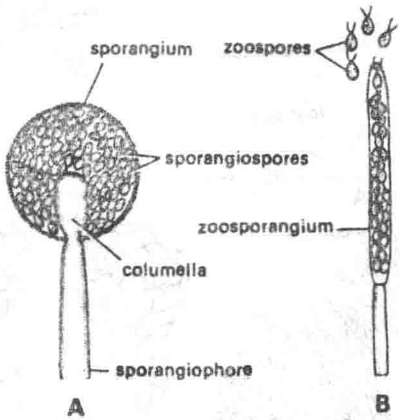

Fig 1.4 A, A sporangium and sporangiospores; B, a zoosporangium and zoospores

b. Conidium and conidiophore: In many fungi (*Aspergillus, Penicillium*) the spores are not contained within membranes, i.e. they are borne free. Such a sporophore is called *conidiophore* and the spores are called *conidia* (Fig. 1.5A). The shape, size, structure, colour and arrangement of conidia are different in different genera and serve as satisfactory points in fungal taxonomy.

Conidiophore may be unbranched (*Aspergillus*, Fig. 1.5A) or branched (*Penicillium*, Fig. 1.5B), and may (*Aspergillus*) or may not (*Penicillium*) contain a vesicle at the end. At the tip of the vesicle or branched conidiophore are present many small, flask-shaped structures, called phialides. The tip of each phialide functions as a growing point and cuts conidia, which remain arranged basipetally, i.e. youngest at the base and oldest at the top on a phialide. In some genera (*Hormodendrum*), however, the conidia develop from the conidiophore by the process of budding. The first-formed spore on the conidiophore develops secondary spores by budding. The ultimate arrangement of conidia is therefore acropetal, i.e. oldest at the base and youngest at the top (Fig.1.5 C).

The type and arrangement of conidiophores and conidia, and the body containing these structures, in some other fungi are given below:

1. In *Trichoderma* the conidia form globular clusters on the conidiophores (Fig. 1.5D).
2. In *Gliocladium* the groups of conidia on different phialides get surrounded by a mass of slime or gelatinous material (Fig. 1.5E).
3. In *Trichothecium* bicelled conidia are formed (Fig. 1.5F).
4. In *Microsporum* (Fig. 1.5G) and *Fusarium* more than one type of conidia are formed. Of these, some are small, unicellular and are called *microconidia*, whereas others are large, multicellular and are called *macroconidia*

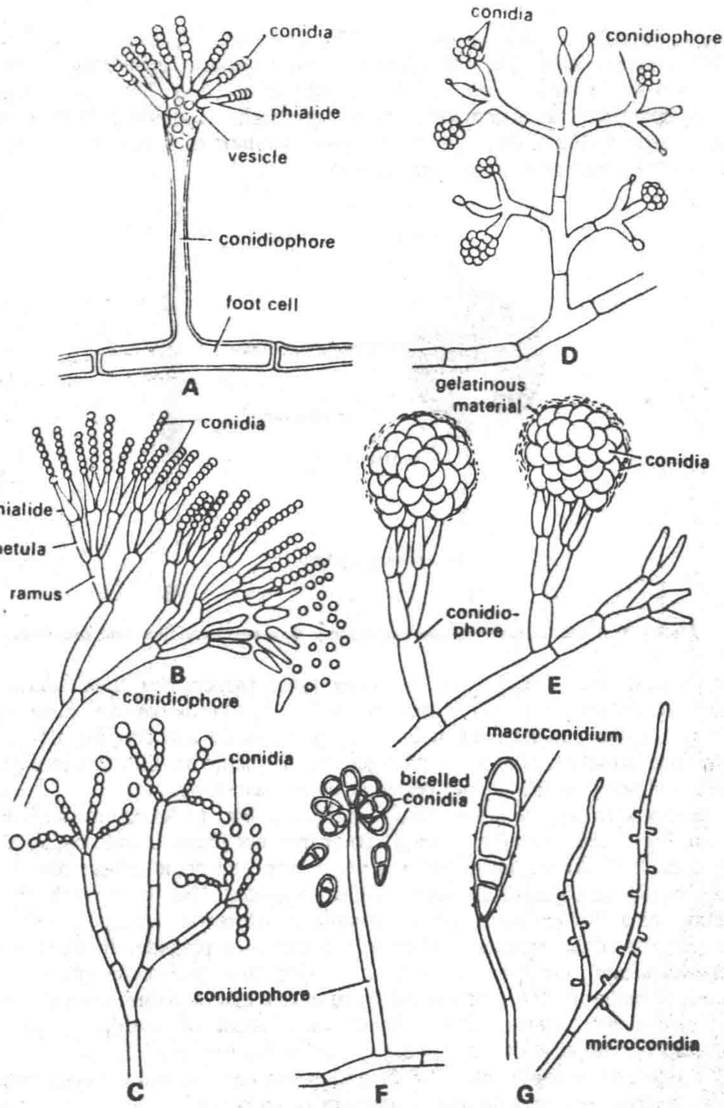

Fig. 1.5 Conidia and conidiophores of some fungi. A, *Aspergillus*; B, *Penicillium*; C, *Hormodendrum*; D, *Trichoderma*; E, *Gliocladium*; F, *Trichothecium*; G, Microconidia and macroconidium of *Microsporum*

5. In *Ceratocystis ulmi* and *Arthrobotryum* group of conidiophores cement together to form an elongated, spore-bearing structure, called *synnema* or *coremium* (Fig. 1.6A).