Indira Gandhi National
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School of Sciences

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BIODIVERSITY (MICROBES, ALGAE, FUNGI AND ARCHEGONIATES)

Block

3

FUNGI

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BLOCK 3 FUNGI

Fungi is an important group of non-chlorophyllous, heterotrophic, eukaryotic organisms that were once thought to be a kind of plants that had lost plastids during the course of evolution. However, fungi are not included in plants because of their different origin and organisation. They are adapted to an absorptive mode of nutrition, whereas animals are characterised by ingestive mode of nutrition. The group fungi comprises true-fungi and fungi-like-organisms.

Fungi live as saprophytes, parasites or in symbiotic association with other plants and animals. As saprophytes they break down organic matter into simple forms that are taken up by other organisms. On the other hand, parasitic fungi such as rust, smut and red rot cause severe diseases in plants and can wipe off crops completely leading to famine. In symbiotic association they live with photosynthetic algae as in lichens and mycorrhiza around the roots of higher plants. So we find that fungi are a very important group of organisms and therefore they must be studied in detail.

Since ancient times fungi have been used to make dairy products and alcoholic beverages. The discovery of yeast as the causative agent of alcohol fermentation greatly helped our understanding of the mechanism of respiration, recognition of enzymes and laid the foundation of modern biochemistry. Today large scale production of organic chemicals – citric acid, lactic acid, glutamic acid; antibiotics – penicillin, cephalosporin; industrial enzymes – diastase, pectinase, cellulase; compounds of medicinal importance – ergot alkaloids and many steroids involve use of fungi such as *Aspergillus, Penicillium, Mucor, Claviceps, Cephalosporium, Trichoderma* and others. A well known plant growth regulator gibberellin was originally discovered as a fungal product of *Gibberella fujikuroi* which parasitises rice plant.

Study of fungi and their biology has greatly helped to understand many basic problems in Life Sciences. The work of Beadle and Tatum on *Neurospora* led to the discovery of how genes (DNA) determine the structure and production of enzymes generally known as 'one gene-one enzyme' hypothesis.

Detailed investigation of the life cycle of parasitic fungi like *Puccinia* by K.C. Mehta helped farmers in India to save the wheat crop from the destructive rust disease.

In a tropical country like India because of excessive moisture, cereals, pulses, groundnuts and other plant produce used as food get infected with a common fungus *Aspergillus flavus*. It produces a powerful toxin called aflatoxin. Some fungal species of mushrooms are edible and some are poisonous to humans.

The mycorrhizal association of fungi with roots of fruit trees and those that inhabit barren soil help the roots to absorb phosphate by solubilising the insoluble phosphate minerals present in the soil. The soil fungi play an important role in the decomposition of vegetable and animal organic matter and help in recycling of carbon, nitrogen and other elements in nature.

In this block you would study various aspects of fungi in 3 units - 9, 10 and 11.

In Unit 9, you would be introduced to general characteristics, ecology, significance, range of thallus organisation, nutrition, reproduction and classification of fungi. In Unit 10, you would learn the characteristics, ecology and significance of true-fungi. You would also study the life cycles of some representative genera of true-fungi. In Unit 11 the general characteristics and significance of symbiotic association of fungi in lichens and mycorrhiza are described. You would also learn the reproductive strategies in lichens.

Objectives

After studying this block, you should be able to:

- distinguish fungi from other groups of organisms;
- classify fungi as true-fungi and fungi-like-organisms;
- describe the general morphological features, ecology and the range of thallus organisation in fungi;
- detail the cell wall composition and mode(s) of nutrition in fungi;
- discuss the various modes of reproduction in fungi,;
- appreciate the significance of fungi with special reference to human beings;
- explain the symbiotic relationship of fungi with green algae and cyanobacteria as seen in lichens;and
- describe the mycorrhizal fungi and their significance.

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UNIT 9

FUNGI: INTRODUCTION

Structure

9.1 Introduction
Objectives
9.2 General Characteristics
9.3 Ecology and Significance
9.4 Range of Thallus Organisation
Slime-Moulds
Fungi with Organised Thallus
9.5 Cell Wall
Structure of Fungal Cell Wall
Chemical Constituents of Fungal Cell Wall
Function of Fungal Cell Wall
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9.7 Reproduction
Vegetative Reproduction
Asexual Reproduction
Sexual Reproduction
9.8 Classification
9.9 Summary
9.10 Terminal Questions
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9.1 INTRODUCTION

It is estimated that there exist around 1.5 million species of fungi. Of these about 1,20,000 have been described so far. Fungi are eukaryotic, spore bearing, achlorophyllous organisms, have absorptive mode of nutrition, reproduce by sexual and asexual methods and their cells have distinct cell walls.

Singular - Fungus
Plural - Fungi

In this unit you would study general characteristics, range of thallus organisation, modes of nutrition, cell wall composition and reproduction in fungi. You would also study the characters on the basis of which fungi are classified and some classifications of fungi that would be followed in this and the subsequent units of this block.

Objectives

After studying this unit you, will be able to:

- enlist the general characters of fungi;
- distinguish between the terms 'True Fungi' and 'fungi-like organisms';
- compare the range of thallus organisation in fungi;
- explain the chemistry and organisation of cell wall in fungi;
- discuss the nutritional habits of fungi;
- describe the habitats, ecology and significance of fungi; and
- detail and compare the various modes of reproduction in fungi.

9.2 GENERAL CHARACTERISTICS

Fungi constitute a group of organisms which exhibit considerable variations in form, behaviour and life cycle patterns. Their distinguishing characteristics are as follows:

- Distribution: fungi are cosmopolitan in distribution.
- Ecological role: ranges from being saprotrophs, biotrophs (parasites or hyperparasites) or mutualists (symbionts).
- Habitat: inhabit terrestrial, freshwater and marine habitats.
- Atmospheric conditions: majority of fungi are aerobes. However, a few species are capable of facultative anaerobic existence. Rarely, they are obligate anaerobic even in the presence of oxygen.
- Thallus: unicellular, filamentous, have non-motile mycelium or hyphae. They grow on or in the substratum. Hyphae show conspicuous protoplasmic streaming. The growth of hyphae is apical.
- Nucleus: fungi are eukaryotic, uni- or multinucleate, homo- or heterokaryotic. Their hyphal cell may possess haploid, diploid or dikaryotic nuclei. Diploid phase could be of variable duration.
- Nutrition: they exhibit heterotrophic mode of nutrition, feeding by absorption rather than ingestion.
- Cell division: the nuclear membrane remains intact through the stages of mitosis until late telophase. This type of cell division is called intranuclear.
- Cell wall: have conspicuous cell walls made up of glucans and chitin. Cellulosic cell walls are present in some taxonomic groups of fungi.
- Life cycle: exhibit simple or complex life cycles.
- Reproduction: is asexual, sexual or parasexual.
- Spores: produce small, microscopic non-motile spores in large numbers. Motile spores are confined to certain groups of fungi, e.g., chytrids. When present the flagellum is either whiplash or tinsel type and is/are one or two per spore.
- Sporocarp and sorocarp: the spore bearing structure, the fructifications ranges from micro- to macro-scopic, sometimes with limited tissue differentiation. These are with or without cell wall covering, termed sporocarp and sorocarp respectively.
- Conditions for growth: they do not require light for somatic growth but exposure to light is necessary for the induction of reproductive structures.
- Reserve food: it is mainly glycogen, lipids or trehalose.

You would study the above characteristics in detail in the following sections.

Facultative – occurring optionally in response to circumstances rather than by nature.

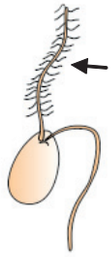
Obligate – restricted to a particular function or mode of life.

Heterokaryotic – a bi- or multi-nucleate cell having genetically different kinds of nuclei.

Dikaryotic – a pair of distinct, unfused nuclei in the same cell brought together by union of plus and minus hyphae in certain mycelia.

Flagella whiplash type – relatively long, whip-like, centriole-based locomotor organelles in some motile cells.

Flagella tinsel type – flagella having lateral filaments known as mastigonemes perpendicular to the main axis. See arrow.



SAQ 1

a) Indicate which of the following statements are true and which are false.

i) Fungi exhibit heterotrophic mode of nutrition, i.e., by ingestion.

ii) The nuclear membrane in fungal cell remains intact throughout the stages of mitosis.

iii) Motile spores are confined to only certain groups of fungi.

iv) Spore-bearing fructifications covered with cell-walls are called sorocarp.

b) In the following statements fill in the blanks with appropriate words:

i) The cell-walls of most of the fungi are made up of glucans and ..... .

ii) An obligate anaerobic fungus can survive even in the absence of ..... .

iii) The mode of reproduction in fungi is asexual, sexual or ..... .

iv) The mode of nutrition in fungi is ..... .

9.3 ECOLOGY AND SIGNIFICANCE

True Fungi and fungi-like-organisms are abundant and widespread in nature. They can inhabit any habitat on Earth as they possess the ability to utilise the substrates that contain traces of organic matter. Hence, they occur as saprophytes, parasites or on dead remains of organisms including other fungi. In the process they release, recycle nutrients, especially carbon, nitrogen and phosphorus. Their antiquity, longevity, ubiquitous distribution in the biosphere and their ability to adjust to a wide range of environmental conditions have made them one of the most successful group of organisms. Fungi are represented by a large number of species, estimated to be next only to the insects.

Normally fungi grow between 0^{o} to 30^{o}C with an optimum temperature range of 20^{o} to 30^{o}C. Many fungi tolerate low temperature of 5^{o} to 6^{o}C or even below the freezing limits. You may have noticed oranges rotting in the fridge. Some fungi can survive temperatures as high as 50^{o}C. Fungi can tolerate highly hypertonic medium. For example, they can grow on jelly, squashes and pickles. In contrast to bacteria, fungi prefer an acidic medium for growth. A pH of around 6 is optimum for most of the fungi investigated.

Table 9.1 provides you an overview of Ecology and significance of the major divisions of fungi-like-organisms. These are other than those belonging to True Fungi. Similarly, Table 9.2 lists some major diseases of crop plants and their pathogens belonging to fungi-like-organisms.

You would study the ecology and significance of true-fungi in Unit 10.

Table 9.1 : Ecology and Significance of Fungi Like Organisms

Division		Ecology and Significance
Slime-moulds (Protists)	Myxomycota	Cosmopolitan, found in lawns, flower beds, wood chips, bark, decaying logs, dead leaves, organic matter, rotting lumber and on many other sources.
	Acrasiomycota	On dead plants, rotting mushrooms, dung, moist soil.
	Dictyosteliomycota	On dung, soil, decaying mushrooms, plant debris.
	Plasmodiophoromycota	Parasitic on fresh water algae, water moulds, aquatic plants and land plants (refer Table 9.2).
Stramenopile	Labyrinthulomycota	Estuarine, in guts of echinoderms and sponges, on plant debris, organic debris, saprophytes or weak parastites, endobiotic in algae, nectrotrophic parasite on shell less molluscs.
	Hyphochytridiomycota	Parasitic on many algae, fungi, saprophyte on plant and insect debris.
	Oomycota	Common in well aerated fresh water streams, rivers, ponds, lakes, near shores and banks of shallow water bodies, as anaerobes in stagnant waters.Saprobes on dead remains of plants and animals, recycle minerals in aquatic ecosystems, parasitic on algae, rotifers, nematodes, mosquito larvae, crayfish larvae, pathogens of a number of crop plants (refer Table 9.2)

Table 9.2 : Some Plant Diseases Caused by Slime-moulds and Stramenopilous Fungi

Slime-moulds	**Myxomycota**	*Physarus sp.*	Diseases of turf grass, vegetables, ornamentals
	Plasmodiophoromycota	*Plasmodiophora brassicae*	Club-root of crucifiers
		Spongospora subterranea	Powdery scab of potatoes
		Polymyxa graminis	Root disease of cereals
Stramenopile	**Oomycota**	*Phytophthora infestans*	Late blight of potato
		Albugo candida	White blisters of crucifers
		Plasmopara viticola	Downy mildew of grapes
		Peronospora parasitica	Downy mildew of crucifers
		Pythium debaryanum	Damping off diseases of seedlings
		Sclerospora graminicola	Downy mildew of millets

SAQ 2

a) Choose the correct answer in the following:

i) Ideal optimum pH for fungal growth is (6/8).

ii) Most slime-moulds are placed in the division (Oomycota / Myxomycota).

iii) Fungi thrive best at the temperature ranges of (5^{o}- 6^{o} / 20^{o}- 30^{o}C).

iv) Parasitic slime-moulds belong to division (Plasmodiophoromycota / Acrasiomycota).

b) Match the diseases caused by fungi given the Column I with the casual organisms given in the Column II.

Column I	Column II
1) Late blight of potato	i) *Plasmodiophora brassicae*
2) Damping off diseases of seedlings	ii) *Phytophthora infestans*
3) Club-root of crucifer	iii) *Albugo candida*
4) White-blisters of crucifer	iv) *Pythium debaryanum*

9.4 RANGE OF THALLUS ORGANISATION

True fungi and fungi-like-organisms exhibit a wide range of thallus organisation. When we observe a fungus, we may be looking at its **anamorph** or **teleomorph** or both of them - the **pleomorph**. A complete range of forms a fungus exhibits in its life cycle constitutes its **holomorph**. Let us now study the morphology of common thallus structures.

Anamorph	Teleomorph	Pleomorph
A form that remains same throughout the life of a fungus.	A form which includes sexually produced spores.	A combination of an anamorph and a teleomorph.

9.4.1 Slime-Moulds

Slime-moulds represent fungus-like-organisms. They are more akin to protozoans in their somatic phase. For most of their life they lack cell walls and grow as protoplasmic mass or as amoeboid cells (Fig. 9.1 & 9.2). The

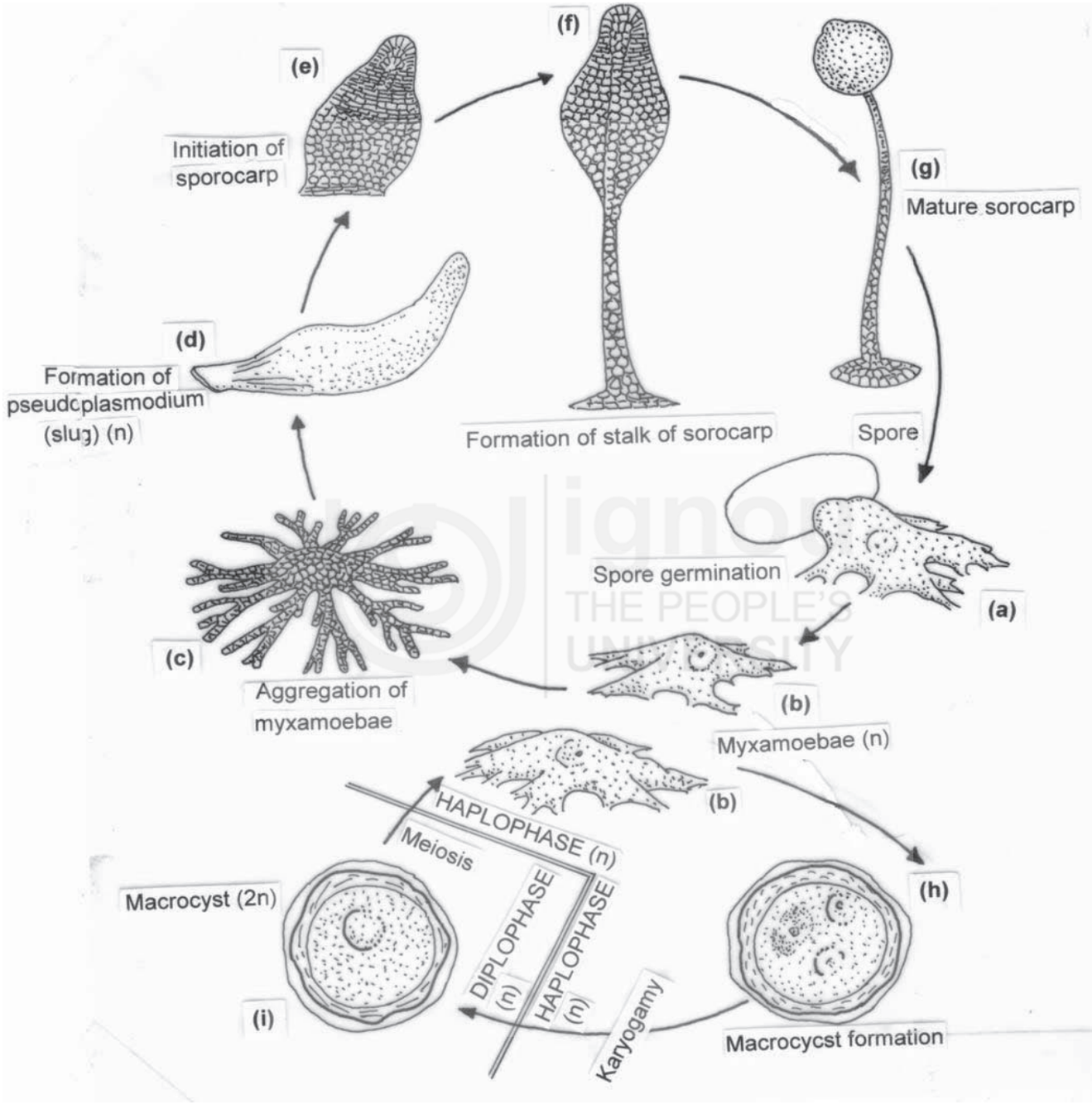


Fig. 9.1 : ***Dictyostelium discoideum*, life cycle. The haploid amoeba known as myxamoeba; b) is free living in soil. Two amoebae (myxamoebae) of compatible mating type meet (h) and a diploid macrocyst (i) is formed. The macrocyst remains dormant for some time and thereafter by undergoing meiosis followed by mitosis forms several haploid myxamoebae. Under unfavourable conditions like starvation, the myxamoebae aggregate; c) and form a pseudoplasmodium; d). The pseudoplasmodium is also known as slug. The slug then forms a sorocarp (e, f, g) in which each amoeba gets converted into spores (see a). These spores are formed asexually and no meiosis is involved in their formation. The spore germinates and forms myxamoebae. Adapted from Alexopolous et al., 2002.**

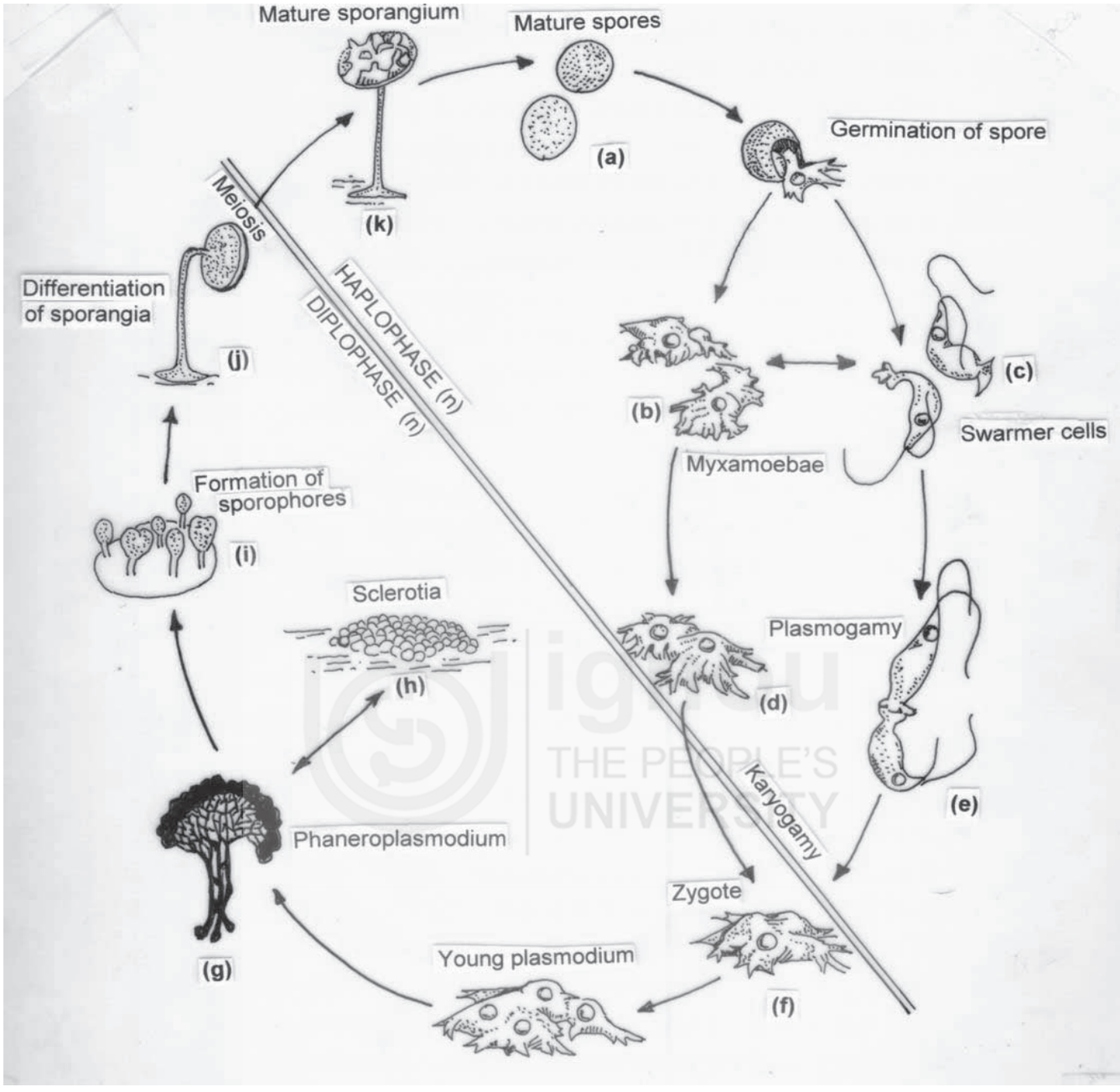


Fig. 9.2 : Life cycle of a heterothallic slime mould. Haploid spores are released from the sporangium (a). After the germination of spore either a myxamoeba (b) or swarmer cell (c) is formed. Myxamoeba and swarmer cells are interconvertible. Myxamoeba can divide mitotically (d) or plasmogamy takes place between the swarmer cells of different mating types (e), this is followed by karyogamy. The diploid zygote (f) forms a phaneroplasmodium (g). If there are unfavourable conditions at this stage, the phaneroplasmodium forms scerotia (h). If conditions become limiting sporophores develop (i). Thereafter, sporangia differentiate (j) in which meiosis occurs and spores are formed (k). Redrawn from Alexopolous et al., 2002.

amoeboid phase is also called myxamoeba (pl. myxamoebae). They may not have definite size and shape. When the myxamoebae aggregate they are termed pseudoplasmodium. A streaming, expanding mass of multinucleate plasmodium is termed as phaneroplasmodium (Fig. 9.2). The nuclei are diploid. At the time of sporulation, distinct cell walls are formed. These spores

are formed in a structure called fruiting body, a sorocarp (Fig. 9.1). However, obligate endoparasitic slime moulds possess multinucleate plasmodial thallus within host cells (Fig. 9.3). A few of the slime moulds are shown in Fig. 9.4.

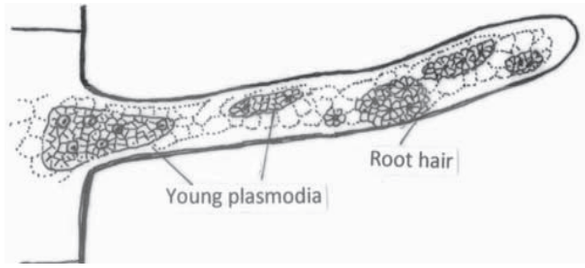


Fig. 9.3: ***Plasmodiophora brassicae*. Young plasmodia within the root hair. Redrawn from Wolf & Wolf, 1949.**

9.4.2 Fungi with Organised Thallus

Except for the types mentioned above, all other fungal groups possess distinct cell walls almost throughout their life cycle. However, they exhibit a wide range of variation in their thallus organisation.

Unicellular

Fig. 9.4 a-e represents a few examples where fungi are unicellular. They may be with or without rhizoids. The shape could be globose or spindle shaped. Yeast represents the most widely distributed unicellular fungus.

Promycelium

Yeast cells reproduce asexually by budding. These buds may remain attached to the parent cell. When such a chain of buds remain attached to each other, it is termed as promycelium (Fig. 9.4 g).

Dimorphism

Fungus may have more than one kind of hyphae. For example, zoo-pathogenic fungi are unicellular in host but are mycelial in culture. A phytopathogen, *Taphrina*, is mycelial in host but unicellular in culture.

Filamentous Forms

Most fungi are filamentous. You may have noticed on a piece of stale bread a web of very fine and delicate threads. These are formed when a fungal spore lands on the bread and germinates into a small tube like outgrowth, which further grow as transparent, tubular filaments in all directions. Each of these filaments is called hypha, the basic unit of fungal body. The mass of interwoven hyphae constituting the body of a fungus is called mycelium (Fig. 9.4 i, j). It may consist of highly dispersed hyphae, or it may be cottony mass of hyphae. The aerial hyphae that bear reproductive structures are called reproductive hyphae. The fungal mycelium has an enormous surface to volume ratio and is close to the food source. This large surface to volume ratio is a marvellous adaptation for absorptive mode of nutrition.

The mycelium of fungi is covered with a cell wall. The protoplasm of mycelium may be continuous throughout the cyloplasm. Such non septate hyphae are observed in the division Oomycota and Zygomycota (Fig. 9.4 h,i). The

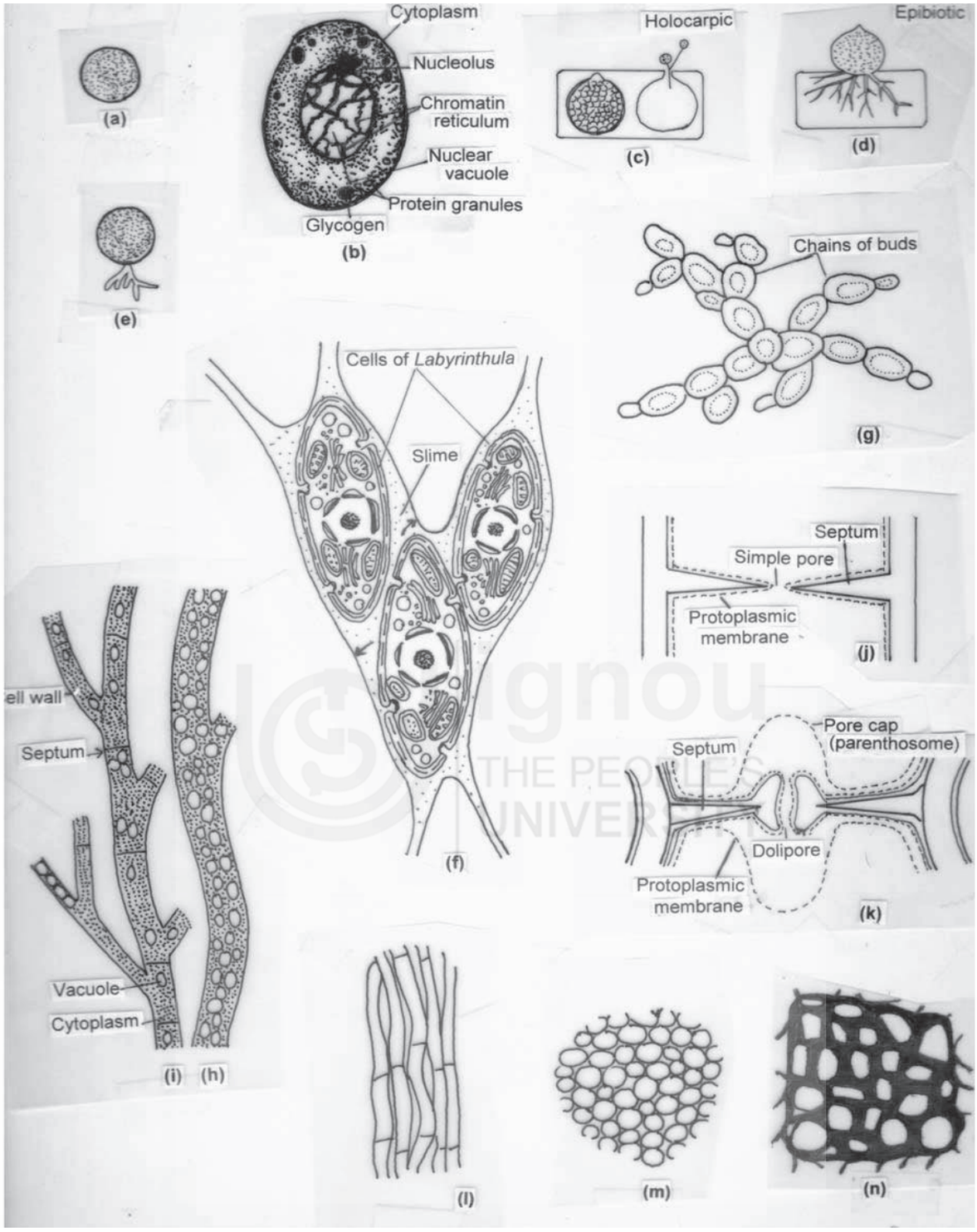


Fig. 9.4: Range of thallus organisation: a) Unicellular – *Hyphochytrid* globose; b) Unicellular – *Saccharomyces* (yeast) oval; c) Unicellular – Holocarpi-endobiotic chytrid-pyriform; d) Unicellular – eucarpic – epibiotic chytrid with rhizoids; e) Unicellular – hypochytrid with rhizoids; f) Unicellular – *Labyrinthula* - spindle shaped with ectoplasmic network (arrow); g) Promycelium – *Saccharomyces*; h) Filamentous – Aseptate - Oomycota; i) Filamentous – Septate - Basidiomycota, Ascomycota; j) Septum – incomplete - Ascomycota; k) Septum – dolipore - Basidiomycota; l) Pseudoparenchyma – Basidiomycota, Ascomycota; m,n) Plectenchyma - Ascomycota, Basidiomycota.

members of division Ascomycota and Basidiomycota develop internal cross walls, the septa which divide the hyphae into segments. These septae occur at regular intervals (Fig. 9.4 i). The septum could be incomplete (Fig. 9.4 j) or dolipore (Fig. 9.4 k). The segment may possess one, two or many nuclei. You would study details of such mycelial structures in next unit.

Plectenchymatous Forms

The fungus mycelium normally, as mentioned above, is a mass of loosely interwoven hyphae which form a network. In some fungi the entire mycelium or its parts undergo various modifications. The walls of the hyphae in the mass get fused and they lose their individuality. As a result the hyphal mass, in cross section appears to be a continuous structure. It resembles the parenchymatous tissue of higher plants, but it is not a true parenchyma as found in higher plants. In fungi such a tissue is called **plectenchyma** (Fig. 9.4 l-n).

Plectenchyma can further be differentiated into two types. The plectenchyma with rounded fungal cells is called **pseudoparenchyma** and with less compacted elongated cells is called **prosenchyma**.

9.5 CELL WALL

Similar to plants but unlike the animals, the hyphal cells of fungi are surrounded by cell wall. Although the chemical components of cell walls can vary between and within different groups of fungi, the basic design seems to be uniform. The fungal cell wall is a dynamic structure. It can change and undergo modifications at different stages in the life of a fungus.

9.5.1 Structure of Fungal Cell Wall

In composition, the fungal cell wall can be distinctly divided in two regions outer and inner. The outer region consists of gel-like or crystalline matrix of water soluble substances. The porous nature of this region determines the permeability of the cell wall. The inner region consists of a network of water insoluble micro-fibrillar scaffold. These fibres are cross linked. The degree of cross linking determines the plasticity of the cell wall.

9.5.2 Chemical Constituents of Fungal Cell Wall

The following are the major fungal cell wall components. Their presence and relative proportions can vary in different fungal groups.

Chitin : These are microfibrillar bundles of linearly linked β–(1,4)–N–acetyl glucosamine chain.

Glucan : These are highly branched with either β-(1,3) or β-(1,6) bonds. These glucans (glucose polymer) are insoluble in alkaline solutions. However, β-1,3 or β-1,4 linked branched or unbranched glucan chains are alkaline soluble. Hence, they contribute to matrix.

Cellulose : These are β-(1,4) glucan chains, found only in the members of Oomycota and are characteristically absent in True Fungi.

Chitosan : These are chitin fibres modified by partial or complete deacetylation to produce poly–β–(1,4) glucosamine. Such chitosan fibres are cross linked by polysaccharide, glucoronic acid and neutral sugars. Chitosan is predominately found in Zygomycota.

Proteins : Proteins are important constituents of fungal cell walls. As enzymes they are involved in synthesis as well as lysis of cell wall and in extra cellular digestion. The structural cell wall proteins can be modified by glycosylation (attachment of oligosaccharides chains to polypeptides). Proteins attached to the surface of cell walls determine the surface properties of adhesion and recognition.

Miscellaneous : In addition to above chemical components the fungal cell wall may contain lipids, melanin, D-galactosamine polymers and polyuronoids.

Chitin, the most characteristic cell wall component of most of the fungi is synthesised by a specialised cell organelle, **chitosome**. An enzyme chitin synthase plays an important role in the biosynthesis of chitin.

The structural formulae of the principal fibrous components of fungal cell walls in given in Fig. 9.5, Table 9.3 provides you an overview of the composition of cell walls in the vegetative thali of major fungal phyla.

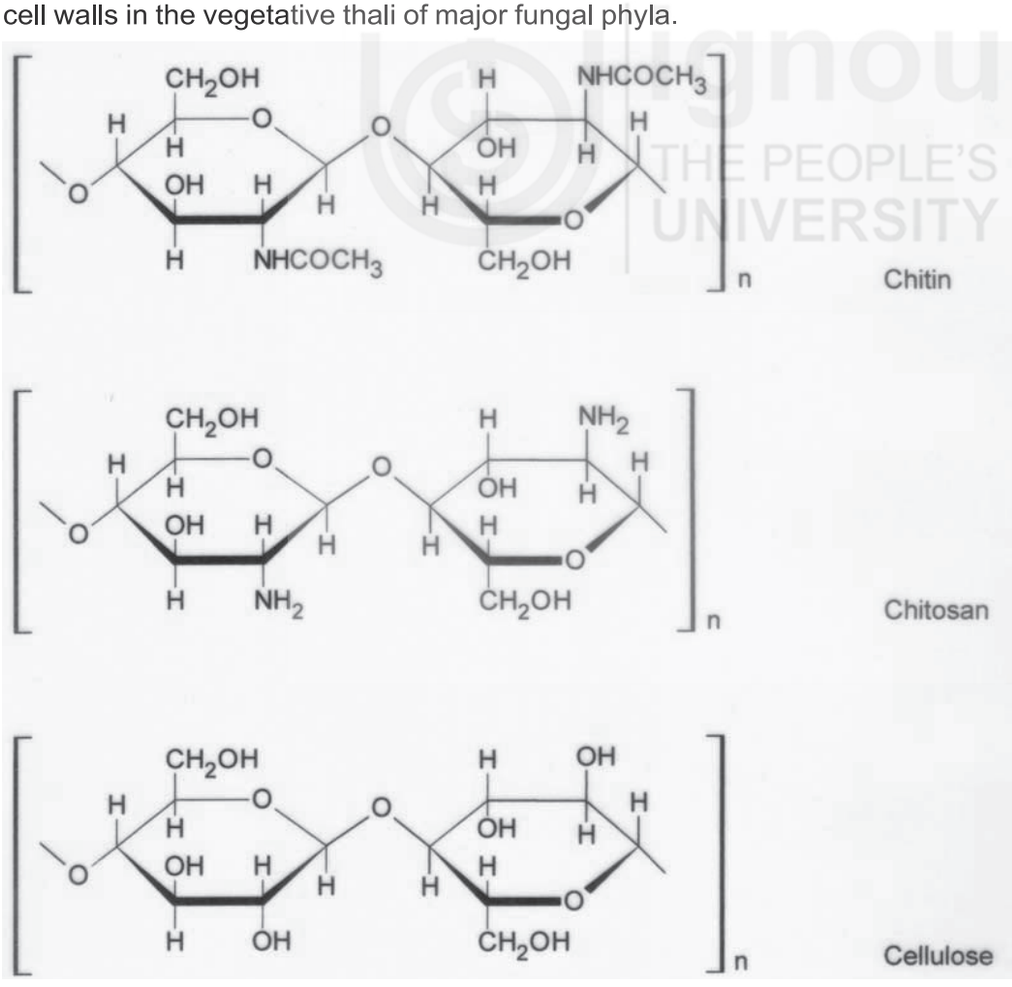


Fig. 9.5 : Structural formulae of the principal fibrous components of fungal cells walls.

Table 9.3: Composition of Cell Walls in Somatic Thali of Major Fungal Divisions

Division	Chitin	Cellulose	Glucan	Protein	Lipid
Oomycota	Absent	Present	Present	Present	Present
Chytridiomycota	Present	Absent	Present	Present	Uncertain
Zygomycota	Present* (Chitosan)	Absent	Present	Present	Present
Ascomycota	Present	Absent	Present	Present	Present
Basidiomycota	Present	Absent	Present	Present	Uncertain

9.5.3 Function of Fungal Cell Wall

The major functions of the cell wall in fungi are to :

- help contain turgour pressure,
- confer shape to the hypha,
- determine permeability,
- protect the protoplast,
- recognise events associated with sexual reproduction, and
- help interaction of fungi with plant and animal symbionts.

9.6 NUTRITION

Heterotrophic – Organisms that fulfil their nutritional requirements by organic substances.

Fungi have no chlorophyll and hence they adopt heterotrophic mode of nutrition. They live as saprophytes, parasites or symbionts.

Saprophytic fungi secure their nourishment from organic substrates present in their surroundings. They are also called **saprobes.** They first digest it by extracellular secretion of hydrolytic enzymes and then absorb it. For instance, bread mould secretes enzyme amylase for digesting starch in the bread converting it to glucose, which can readily be transported across the plasma membrane of the mycelium. Such a mode of nutrition is called heterotrophic. It is more by absorption rather than ingestion. Fungi can uptake organic/ inorganic solutes from extremely dilute solutions from their environment. Lipid bilayer in fungal cell walls are principle impediments for uptake of water soluble substances. Uptake of such substances is mediated by pores in proteinaceous components of membranes. Such pores may be selective to a particular substrate. They are termed channels. The transfer of substances through **channels** is passive and along the concentration gradient. Pores that transfer substances against the concentration gradient are called **porters.** Transfer across porters require expenditure of energy and is termed active. Apical and subapical regions of hyphal tip play an important role in active transfer of substances. However, cellular slime moulds take food by phagocytosis rather than by absorption.

Many fungi live as parasites on plants, animals and humans. Like animal parasites, parasitic fungi are either ectoparasites or endoparasites. You may know that ectoparasites remain on the surface of the host. In ectoparasitic fungi, the mycelia spread on the surface of the host and attach themselves to it through special organs called **appressorium.** A minute infection peg grows from the appressorium and penetrates the epidermal cell of the host tissue for obtaining nourishment. In endoparasitic fungi the mycelium ramifies within the host tissue. The intracellular absorption of food from the host is carried out by haustoria. Some parasitic fungi utilise two hosts for completing their life cycle, e.g., *Puccinia graminis* about which you will learn in the next unit. Some fungi even parasitise other fungi. They are called biotrophic mycoparasites.

Biotrophs – Parasites are also called biotrophs. They may be obligate or facultative. They do not necessarily kill host.

Fungi may be facultative or obligate parasites. The facultative parasites are those which become parasitic under certain stress conditions, while obligate parasites maintain a parasitic mode throughout their life.

Symbiotic fungi live in intimate mutually beneficial relationship with other organisms, often a plant. More about such relationship you will learn in Unit 11. Some fungi also grow on the surface of higher plants without causing noticeable damage.

Nectrotrophs

Parasites that kill the host cells and feed on the dead tissues. They may release toxins to kill host, damaging plasma membranes of host tissue. Nutrients from host get released quickly and is readily available to parasite.

Since fungi are basically heterotrophs they utilise preformed food in nature. In laboratory conditions, however, they require nutrients such as: C, H, O, K, P, S, N, Mg, Zn, Mn, Cu, Fe, Ca, and many others. They, however, can biosynthesise their own vitamins. But they need to be supplied biotine, thiamine, methionine, cysteine externally.

SAQ 3

a) Which of the following statements are incorrect? Write them correctly:

i) The buds produced by yeast are called promycelium.

ii) Septate mycelium is characteristic of Zygomycota.

iii) Chitosan is predominantely found in Zygomycota.

iv) Oomycota is the only fungal division whose cell walls are cellulosic.

v) Those fungi which become parasitic under certain conditions are called obligate parasites.

b) Match the cell-wall components mentioned in column I with the constituent monomers given in the column II:

Column I		**Column II**	
1)	Chitosan	i)	β- (1,4) glucan
2)	Cellulose	ii)	β- (1,4) glucose
3)	Glucan	iii)	β- (1,4)-N-acetyl glucosamine
4)	Chitin	iv)	poly-β- (1,4) glucosamine

9.7 REPRODUCTION

Fungus hypha elongates by apical growth, but most parts of a fungus are potentially capable of growth. When the mycelium of a fungus reaches a certain stage of maturity and accumulates reserve food it starts reproducing. As in algae, reproduction in fungi is of three kinds:

i) vegetative,

ii) asexual, and

iii) sexual.

On the basis of involvement of the thallus in the formation of asexual and sexual reproductive organs fungi are categorised as **holocarpic** and **eucarpic**.

Holocarpic

When the entire fungal thallus is converted into one or more reproductive structures so that vegetative and reproductive phases do not occur together in the same individual, the fungus is called holocarpic.

Eucarpic

In the majority of fungi, the reproductive organs arise from a portion of the thallus, while the remaining portion continues its normal vegetative activities. Such fungi care called eucarpic.

In this section, you would study various strategies of reproduction in fungi including true-fungi.

9.7.1 Vegetative Reproduction

Vegetative reproduction takes place by the following methods: i) fragmentation, ii) fission, iii) budding, iv) oidia, v) chlamydospores, vi) rhizomorphs and vii) sclerotia.

Fragmentation

In fragmentation, which may result from accidental severing of the mycelium into bits of fragments or by mechanical injuries or otherwise, the mycelium breaks into segments of hyphae. Each segment by further division of cells and apical growth develops into a new mycelium under favourable conditions.

Fission

In unicellular fungi like the yeast, the single cell multiplies by fission (Fig. 9.6 a). Here, the parent cell elongates and divides transversely into two daughter cells. First, the nucleus divides, followed by the division of the cytoplasm and wall formation, thus dividing the parent cell into two. The two daughter cells separate and lead independent lives.

Budding

In budding yeast, the cells reproduce by a process called budding. Here, the parent cells put out a small outgrowth which is called a bud (Fig. 9.6 b). The bud gradually enlarges and finally gets separated from the parent cell by a cross wall. This end develops into new individual yeast. Sometimes the bud may produce a new bud before separation from the parent cell and in this way a chain of buds may be produced which finally get separated.

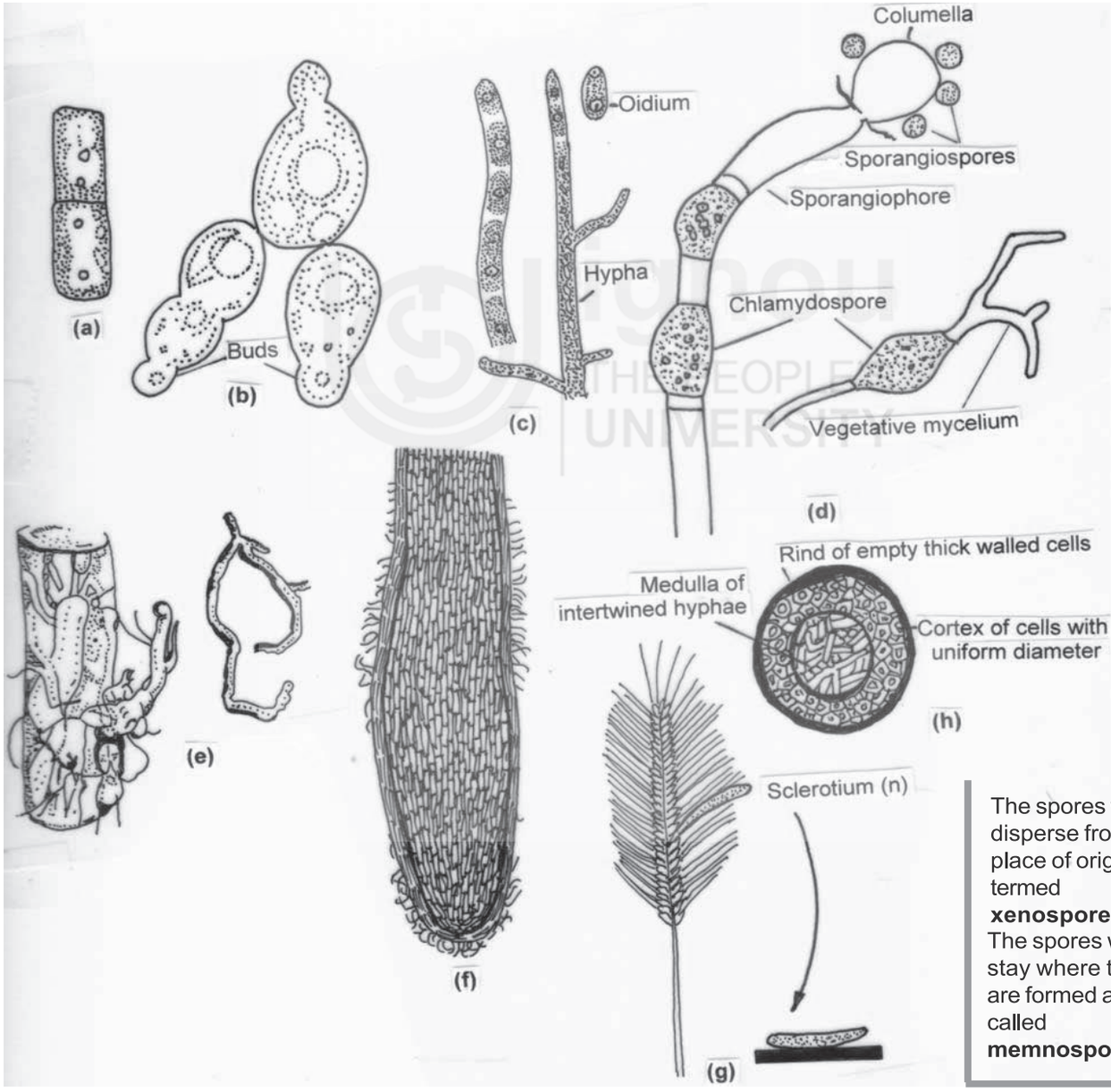
Oidia

In some filamentous fungi, the hyphae break up into individual cells which are called oidia or **arthrospores** (Fig. 9.6c).The cells become rounded or oval in shape and appear like the beads of a rosary. Each oidium or arthrospore develops into a new mycelium.

Chalamydospores

The chlamydospores are one-celled fragments, which function as perennating bodies. They are formed either singly or in chains in the vegetative hypha (Fig. 9.6d). The chlamydospores develop thick, resistant walls and accumulate food materials and thus help the fungus to tide over unfavourable conditions. With the return of favourable conditions each chlamydospore develops into a new mycelium.

The term spore is used for any small propagative, reproductive or survival unit which separates from a hypha or a sporogenous cell and gives rise to a new individual. In a spore, water content and metabolic activities are low, vacuoles are absent and there is cessation of cytoplasmic movement.



The spores which disperse from the place of origin are termed **xenospore**. The spores which stay where they are formed are called **memnospores.**

Fig. 9.6: Vegetative reproduction in fungi : a) Fission; b) Budding; c) Oidium; d) Chlamydospores; e) Whole mount (w.m.) Rhizomorph; f) L.s. Rhizomorph; g) W.M. Sclerotium; h) T.S. Sclerotium.

Rhizomorphs

These are usually dark brown, fine, root-like strands. They (Fig. 9.6 e,f), serve as a means of perennation. Under unfavourable conditions rhizomorphs remain dormant but with the onset of favourable conditions the rhizomorphs resume growth and may also give rise to fruiting bodies.

Sclerotia

You know that sclerotia are also modification of the mycelium. They serve as a means of perennation and vegetative propagation. They may be rounded, cylindrical, cushion-shaped or irregularly shaped with a dense mass of thick walled hyphae. The hyphae form a compact, pseudoparenchymatous tissue (Fig. 9.6 g,h). With the return of favourable conditions a sclerotium germinates to form a new mycelium, e.g., *Claviceps* (ergot).

9.7.2 Asexual Reproduction

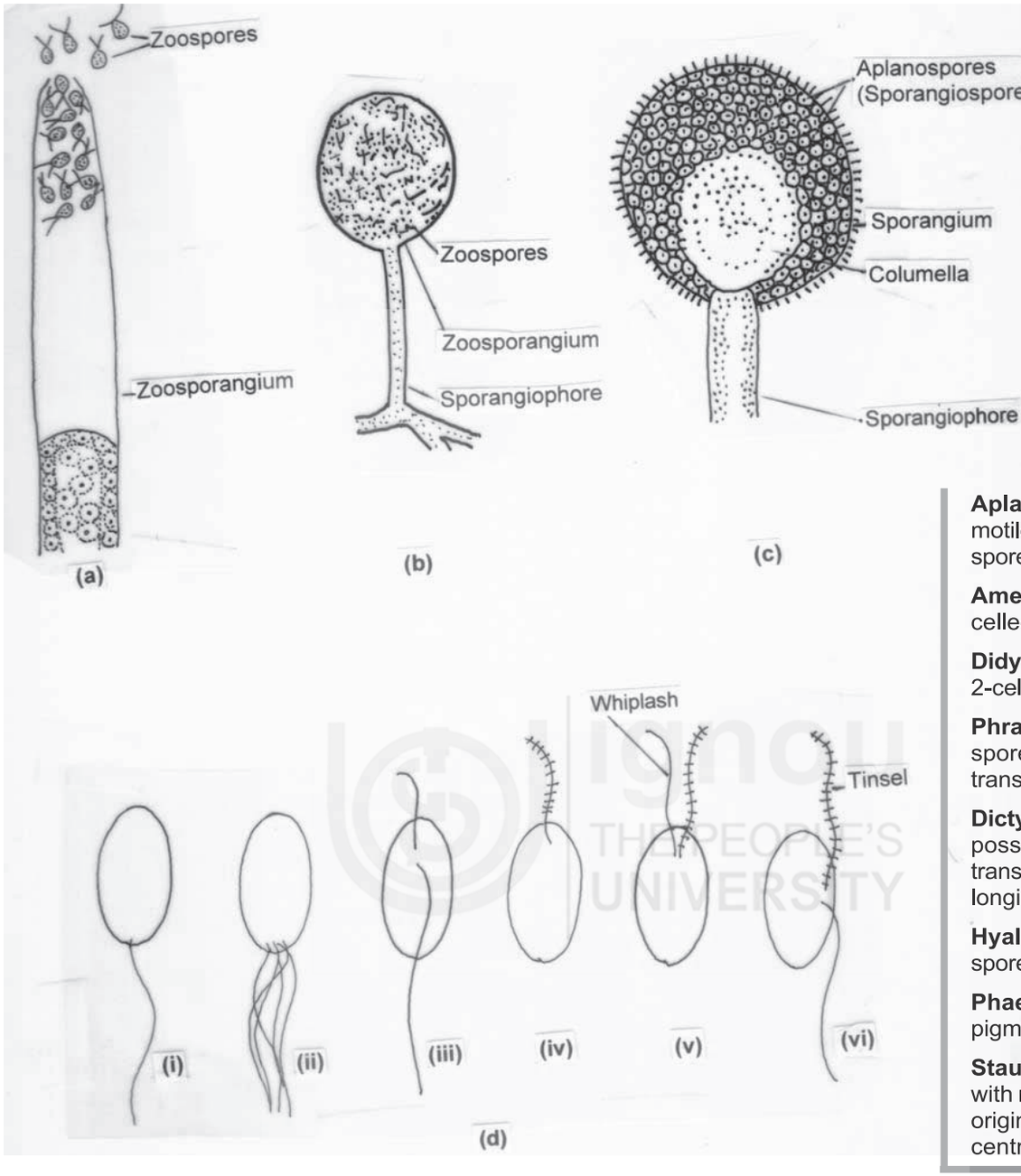
In fungi asexual reproduction is a more common method than sexual reproduction. It is usually repeated several times in a season. It takes place by the formation of special reproductive cells called spores. The process of spore formation in fungi is called **sporulation.** Each spore develops into a new mycelium. These spores are produced as a result of mitosis in the parent cell and hence they are also called **mitospores**. The spores vary in colour, shape and size, number, arrangement on hyphae and in the way in which they are borne.

They are minute to large in size. In shape they vary from globose to oval, oblong, needle-shaped to helical. Thus, an infinite variety of spores can be observed in fungi.

Usually the spores are unicellular. They may be uninucleate or multinucleate. In some fungi like *Alternaria,* they are multicellular. The mitospores produced in fungi are of two types, **sporangiospores** and **conidia** (singular: conidium).

The sporangiospores are produced inside a sac-like structure called **sporangium.** The hypha bearing a sporangium is called **sporangiophore** (Fig. 9.7 b). The sporangiospores may be motile or non-motile. The non-motile sporangiospores are called **aplanospores** (Fig. 9.7 c). These are characteristic of terrestrial fungi such as *Mucor* and *Rhizopus*. In aquatic fungi like *Pythium* of Division Oomycota motile biflagellate sporangiospores are produced. These are called **zoospores** and the sporangium bearing them is called **zoosporangium** (Fig. 9.7 a,b). A zoospore is a motile spore lacking a cell wall. After a swarming period it secretes a wall and germinates to form a germ tube. In contrast to zoospores, the aplanospores have a definite spore wall and are dispersed by wind and insects. Fig. 9.7 d represent differents kinds of flagella and their point of insertions on a zoospore.

The conidia are non-motile, deciduous mitospores formed externally as single separate cells. They develop either directly on the mycelium or on



Aplanospore - non-motile wall-bearing spore.

Amerospore - single celled spores.

Didymospores - 2-celled spores.

Phragmospores - spore with two or more transverse septa.

Dictyospores - spore possessing both transverse and longitudinal septa.

Hyalospore - hyaline spore.

Phaeospore - pigmented spore.

Staurospore - spores with radiating arms originating from a central axis.

Fig. 9.7: Asexual reproduction in fungi: a) and b) Zoospores produced in zoosporangium are motile and without cell wall; c) Aplanospores, produced in sporangium are non motile and possess cell wall; d) Zoospore types found in fungi. (i) Posteriorly uniflagellate zoospore with a flagellum of the whiplash type found in many Chytridiomycota. (ii) Posteriorly multiflagellate zoospore with numerous (up to 16) whiplash flagella which occur in certain anaerobic rumen-inhabiting Chytridiomycota. (iii) Zoospore with unequal (anisokont) whiplash flagella characteristic of the Myxomycota and the Plasmodiophoromycota (iv) Anteriorly uniflagellate zoospore with a flagellum of the tinsel type, the axoneme being clothed with rows of mastigonemes, typical of the Hyphochytridiomycota. (v, vi) Biflagellate zoospores with heterokont flagella, one of the whiplash and the other of the tinsel type, which are found in different groups of the Oomycota.

morphologically differentiated hyphae called conidiophores (Fig. 9.8). The conidiophores may be simple or branched, septate or aseptate. The conidia are produced singly or in chains at the tips of the conidiophores or at the tips of their branches, e.g., *Penicillium.*

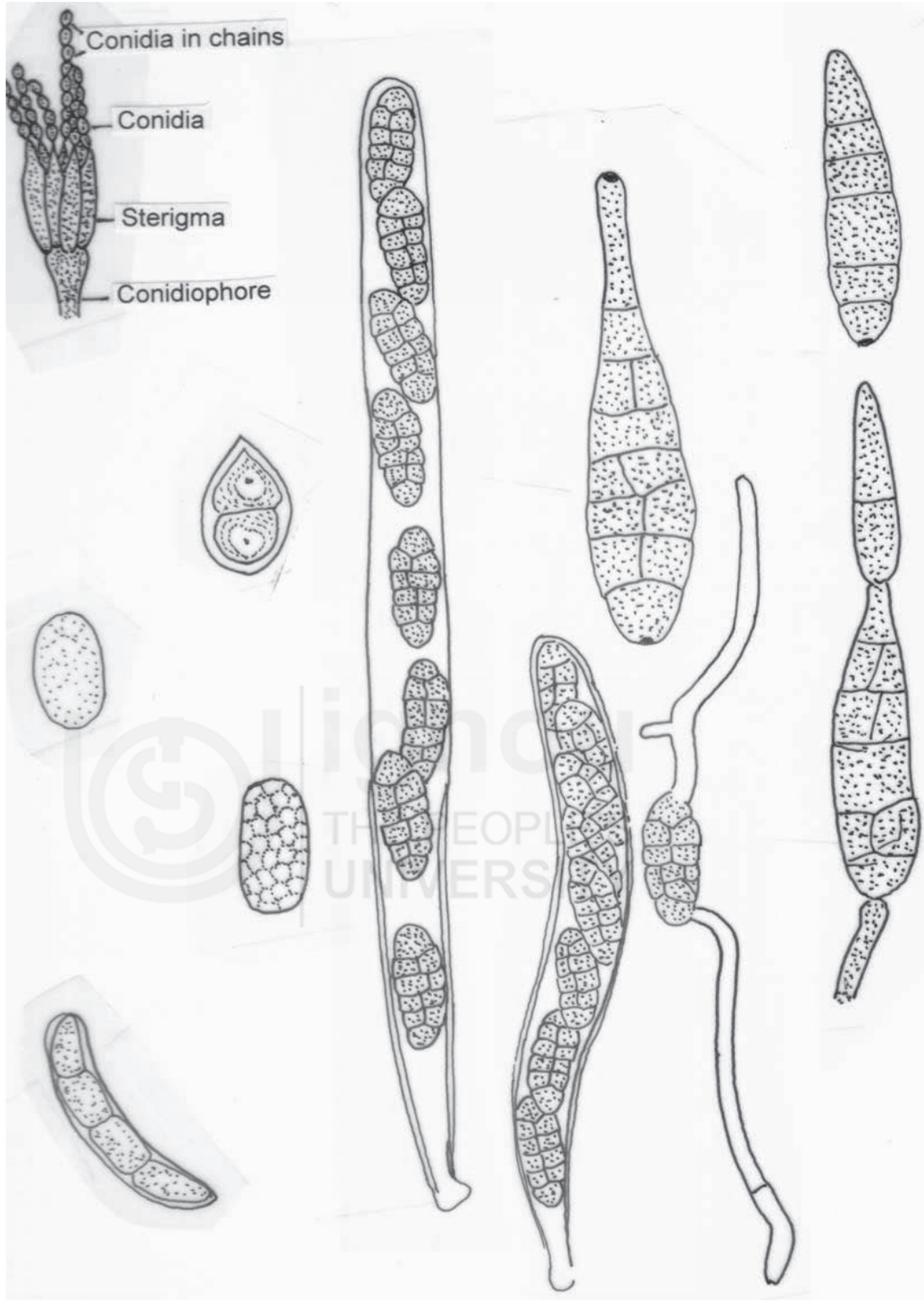


Fig. 9.8 : Asexual reproduction in fungi by conidia. Various kinds of conidia in fungi.

The conidia are non-motile, deciduous mitospores formed externally as single separate cells. They develop either directly on the mycelium or on morphologically differentiated hyphae called conidiophores (Fig. 9.8). The conidiophores may be simple or branched, septate or aseptate. The conidia are produced singly or in chains at the tips of the conidiophores or at the tips of their branches, e.g., *Penicillium.*

Often the conidiophores arise singly and are scattered in the mycelium.
Sometimes they arise in specialised structures called fruiting bodies (Fig. 9.9).

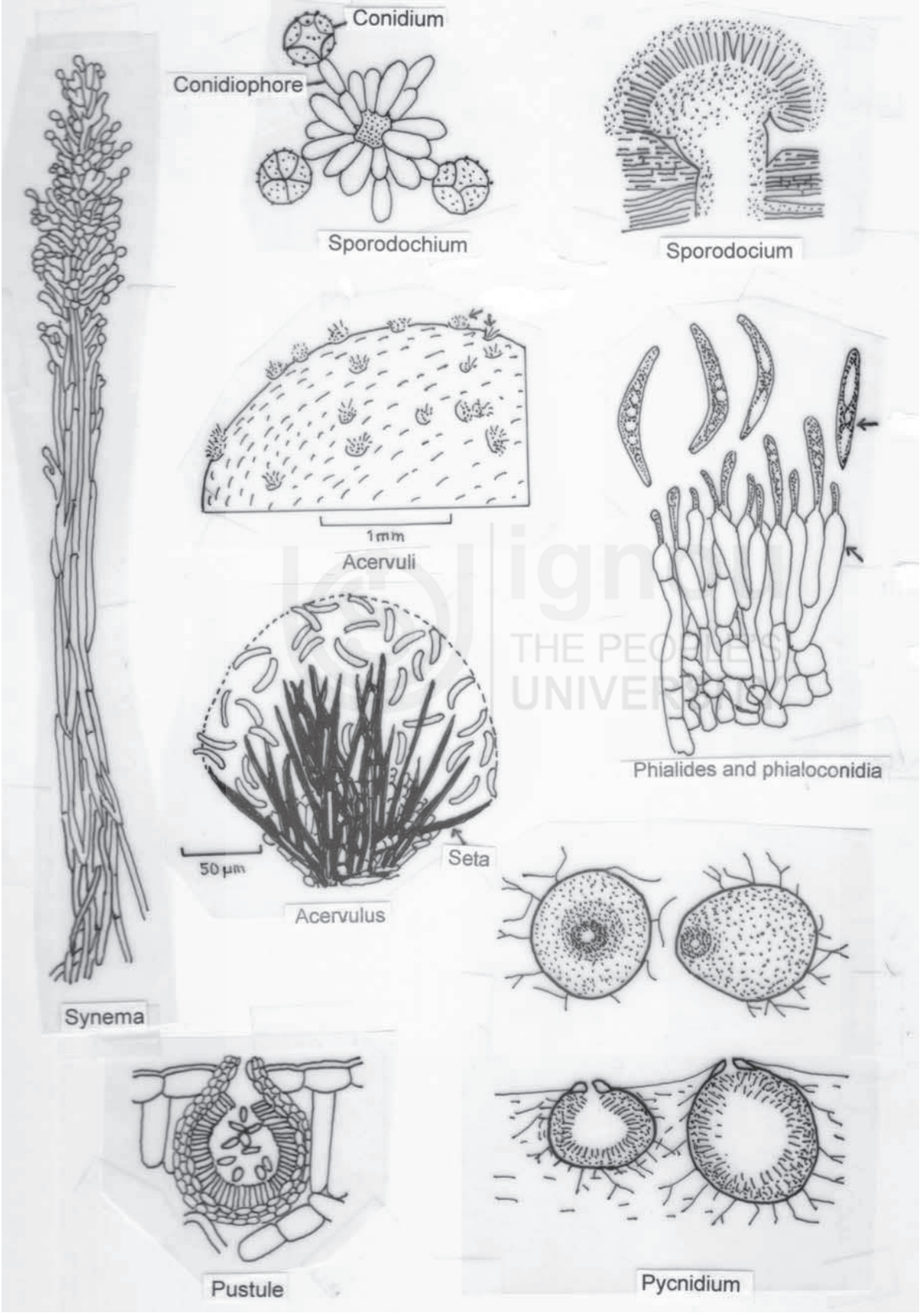


Fig. 9.9: Various types of fruiting bodies in fungi.

9.7.3 Sexual Reproduction

The sexual stage in fungi is called the **perfect state** in contrast to the **imperfect state** which is the asexual stage. Sexual reproduction involves the fusion of two compatible sex cells or gametes of opposite strains. Fungal sex organs are called gametangia. They may be equal in size. In many Ascomycota morphologically different gametangia are formed. The male gametangia are called antheridia and the female ones ascogonia.

A fungus may be homothallic, that is, the fusing gametes derived from the same mycelium or may be heterothallic, that is the fusing gametes are produced from different strains of mycelia.

In fungi, sexual reproduction involves the following three phases: i) plasmogamy, ii) karyogamy and iii) meiosis (Fig. 9.10). These three processes occur in a regular sequence and at a specific time, during the sexual stage of each species.

Plasmogamy: It is the union of protoplasts or reproductive hyphae or cells, one from the male and the other from the female to bring about the nuclei of the two parents close together as a pair. However, the two nuclei do not fuse with each other. Such a cell is called a **dikaryon.** The dikaryotic condition is unique to fungi and may continue for several generations as the two nuclei (dikaryon) divide simultaneously during cell division. These are passed on to daughter hypha.

Dikaryotic state refers to a cell or hypha which contains a pair of closely associated nuclei, each usually derived from a **different parent cell.** The dikaryotic condition is often abbreviated as the n + n condition.

Karyogamy: The fusion of the these two nuclei which takes place in the next phase is called karyogamy. It may immediately follow plasmogamy as in lower fungi, or it may be delayed for a long time as in higher fungi.

Meiosis: Karyogamy which eventually occurs in all sexually reproducing fungi is sooner or later followed by **meiosis** producing four genetically different haploid spores.

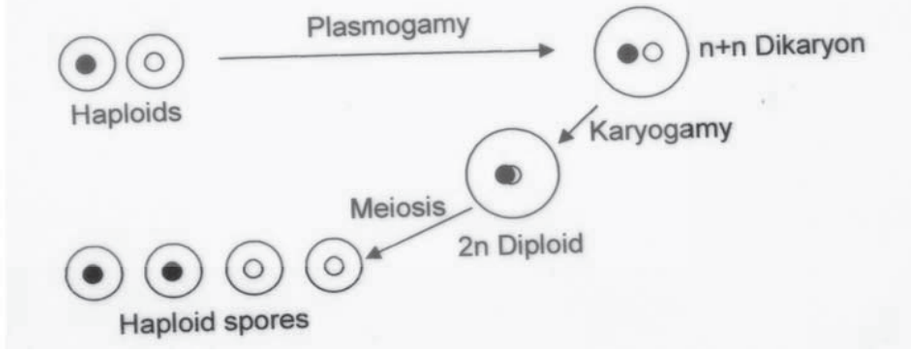


Fig. 9.10: Three phases of sexual reproduction in fungi.

We will now discuss plasmogamy in detail. There are different methods of plasmogamy in fungi.

i) **Planogametic copulation:** It involves fusion of two gametes. Like in algae sexual union in fungi may be **isogamous, anisogamous** or **oogamous** (Fig. 9.11 a). Anisogamy and oogamy are together called

heterogamous sexual reproduction. Isogamy is the simplest type of sexual reproduction, where the fusing gametes are morphologically similar, e.g., *Synchytrium*. Anisogamy, where the fusing gametes are dissimilar is found in one genus, *Allomyces*, a chytrid. In oogamy as you may recall the motile antherozoid enters non-motile oogonium and unites with egg or oosphere forming a zygote. Oogamy is seen in fungi such as *Pythium*, *Albugo*, *Saprolegnia* and *Phytophthora*.

ii) **Gametangial copulation:** The two gametangia make contact and the entire contents of the two fuse together and become one, e.g., *Mucor* and *Rhizopus*. In some fungi the entire protoplast of one gametangium flows into the other through a pore (Fig. 9.11 b). Among the two, the recipient is the female and the donor is the male.

iii) **Gametangial contact:** The male gamete is not a separate entity but the nucleus in the antheridium represents the gamete. As you can see in the Fig. 9.11 c the oogonium and antheridium form a contact through a tube and one or more nuclei inside the antheridium migrate into the oogonium. You may note that in this case the two gametangia do not fuse. It is observed in *Penicillium* (Fig. 9.11 c).

iv) **Spermatisation:** This mode is quite remarkable as the minute conidia like gametes called **spermatia** are produced externally on special hyphae called **spermatiophore** (Fig. 9.11 d).Spermatia may develop inside the cavities called **spermatogonia**. The female cell may be a gametangium, a specialised receptive hypha or even a vegetative hypha, e.g., rust fungi.

v) **Somatogamy:** In higher fungi like Ascomycota and Basidiomycota there is a progressive degeneration of sexuality. The entire process is very much simplified by the fusion of two mycelia which belong to opposite strains (Fig. 9.11 e). The post-fertilisation changes result in the production of a fruiting body which is called **ascocarp** in Ascomycota and **basidiocarp** in Basidiomycota.

The gametangial fusion followed by the fusion of male and female nuclei results in diploid nuclei. Subsequently, reduction division occurs and haploid spores are formed. In fungi, the spores may be formed in specialised structures characteristics of a division (for details refer Unit 10).

9.8 CLASSIFICATION

Fungi have been classified by various mycologists using a combination of characters (see Table 9.4). Earlier, fungi were placed under division **Thallophyta** of subkingdom (Cryptogamia) of kingdom Plantae. Even, the father of systematic biology. C. Linnaeus placed fungi in plant kingdom. But as the microscopic studies progressed, it became evident that fungi are neither plants or animals. **Ernst Haeckel** (1866) proposed a third kingdom, the **Protista** to include such organisms.

Alexopoulos (1962) placed fungi in division **Mycota** and recognised two subdivisions: the **Myxomycotina** (true slime moulds) and the **Eumycotina** (True Fungi).

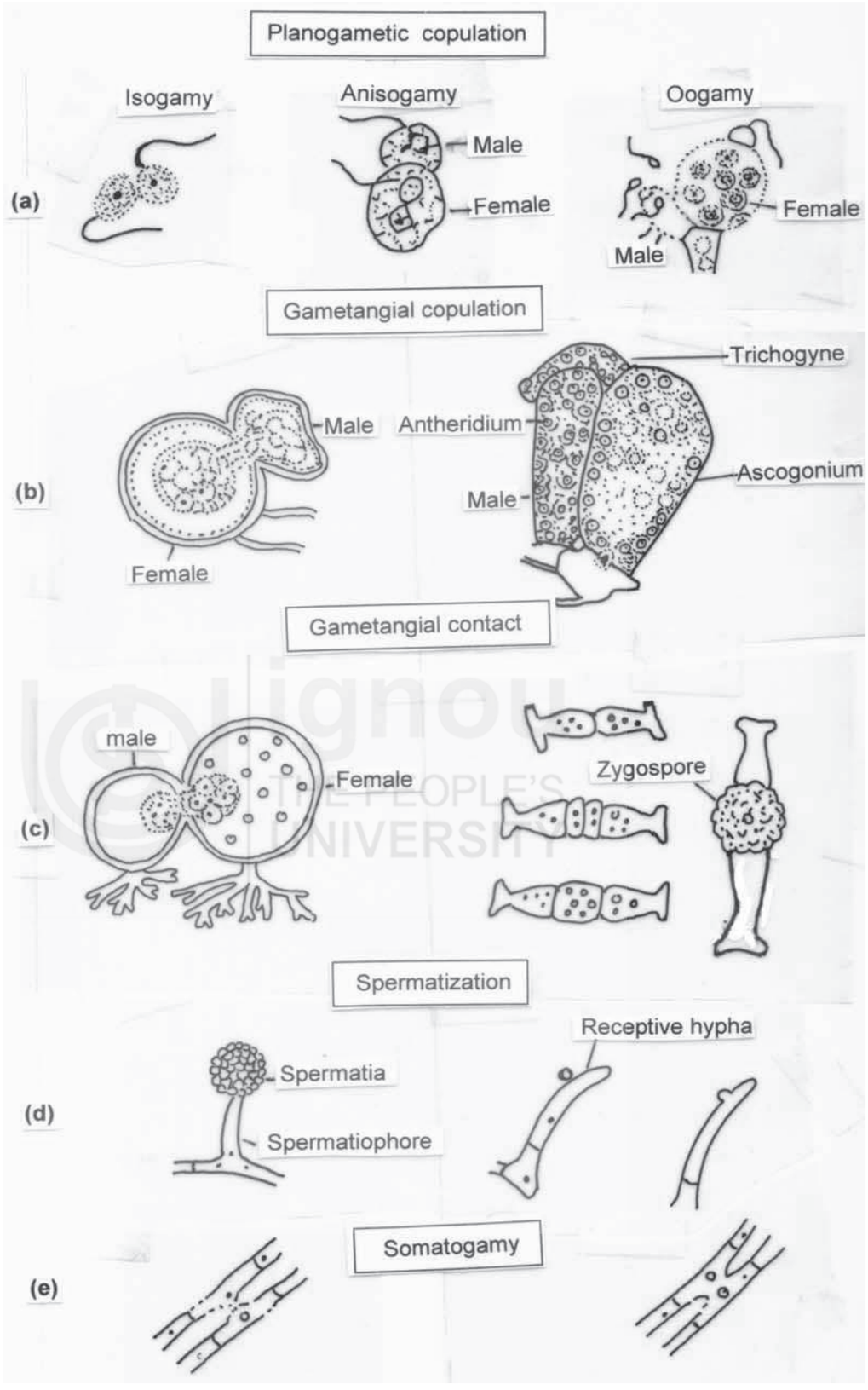


Fig. 9.11: Different ways of plasmogamy in fungi.

Ainsworth (1966) treated fungi as a separate kingdom, with divisions: **Myxomycota** (plasmodial forms) and **Eumycota** (non-plasmodial forms).

Whittaker and **Margulis** (1978) recognised two super kingdoms – **prokaryonta** and **eukaryonta**. Fungi were placed as an independent kingdom **Myceteae** within super Kingdom Eukaryonta.

During last few decades, there have been significant advances in ultra-structural, biochemical and molecular fields. It is universally recognised that all the organisms that we recognise as fungi are not closely related and do not share common ancestry and they are accordingly polyphyletic. Accordingly, in an attempt to recognise monophyletic groups, the organisms once classified as fungi are now considered in three different groups:

i) the monophyletic kingdom **Fungi** (with four divisions); also called True Fungi.

ii) the monophyletic kingdom **Stramenopila** with three divisions, and (iii) four protistist division of slime moulds; certain algal groups such as diatoms, brown algae are also placed in this kingdom.

However, Alexopoulos et. al. (1996) consider all of them as a closely knit group on the basis their morphology nutritional modes and ecology (Table 9.4). The above classification as proposed by **Alexopoulos et al**., 1996, Table 9.5, is followed in this course.

Table 9.4: Prominent Parameters Used in Taxonomy and Classification of Fungi

S. No.	Parameter	Characters
1	Microscopic	Absence or presence of septal hypha; Type, formation and release of spores, biology and ecology of fungi.
2	Ultrastructure	Morphology of septal pores; Details of cell wall; and arrangement of secretory vesicles in the hyphal tip.
3	Biochemical	Chemical composition of cell walls; Alternate pathway of lysine biosynthesis; Occurrence and types of pigments; and Types and amount of sugars and polyols.
4	Molecular	Comparison of DNA sequence; Properties of protein products; Isozyme analysis; RFLP (Restriction fragement length polymorphism); RAPD (Random amplified polymorphic DNA); and Banding patterns or gene sequencing.

Table 9.5: Classification as Proposed by Alexopoulos et al., 1996

Kingdom	Protists[1]	Stramenopila[2]	Fungi[3]
Division	Plasmodiophoromycota Dictyosteliomycota Acrasiomycota Myxomycota	Oomycota Hyphochytridiomycota Labyrinthulomycota Basidiomycota	Chytridiomycota Zygomycota Ascomycota

1. Slime-mould / fungi-like-organisms (do not possess cell wall in somatic phase).
2. Other fungi possess tinsel (stramenopilous) flagellum and cellulosic cell walls).
3. True fungi (possessing chitinous cell walls).

The taxon phylum is equivalent to the term division. In this block taxon term division is employed.

Salient features of divisions of Protists and stramenopila are briefly described below:

Protist Group

Divison: Plasmodiophoromycota: (Endoparasitic Slime-Mould): Vegetative body plasmodial; cell wall absent; pseudopodia distinct. Asexual propagules are motile zoospores. Each zoospore bears two laterally inserted unequal whiplash flagella. The anterior flagellum is shorter than the posterior one, e.g., *Plasmodiophora*, *Spongospora*.

Division: Dictyosteliomycota (Dictyostelid Cellular Slime-Mould): Produce multicellular sorocarp of cellulosic network; asexual propagule, amoebae, exhibit phagocytosis; sexual reproduction is through mating of two amoebae to form a diploid macrocyst, meiosis in macrocyst form haploid amoebae, e.g., *Dictyostelium; Acytostelium; Polysphondylium*.

Division: Acrasiomycota (Acrasid cellular slime mould): Amoebae are cylindrical possessing a single, large lobed anterior pseudopodium. Posterior part of amoebae is knob shaped, amoebae are uninucleate. The sorocarps are branched; produced macrocyst. A macrocyst produces an amoeba. An aggregate of amoebae produce plasmodium. Sexual reproduction unknown, e.g., *Acrasia*.

Division: Myxomycota (True Slime-Moulds): Life cycle exhibits four important phases: (i) Unicellular flagellate or non-motile cells. When motile, cells posses two identical anterior whiplash flagellae; (ii) a multinucleate plasmodial phase; (iii) resistant sclerotium phase; and (iv) sexual sporocarp phase. Under unfavourable conditions myxamoebae produce swarmers; swarmers fuse to produce diploid zygote. Reduction division in zygote produce Myxamoebae. Myxamoebae are also asexual reproductive units, e.g., *Physarum*; *Stemonitis*; *Echinostelium*.

Kingdom: Stramenopila

Division: Oomyota (Water-moulds)**:** Vegetative hyphae sac like or branched thali or mycelial, coenocytic, aseptate. The cell walls are cellulosic, reproduce asexually through motile zoospores, biflagellate, one flagellum tinsel (longer, straminipilous) and one shorter whiplash kind; asexual reproduction oogamous; sex organs termed antheridum (male) and oogonium (female). Meiosis occurs in developing gametangia, e.g., *Phytophthora*, *Plasmospora*.

Division : Hyphochytridiomycota (Hypochytrids)**:** The zoospore possessing one anterior straminipilous flagellum is characteristics of hyphochytrids. The zoospore develops non-motile cyst to pass over unfavourable conditions, e.g., *Hyphochytrium*, *Rhizomyces*.

Division: Labyrinthulomycota (Slime-Net-fungi)**:** A net work of slime within which vegetative cells are present, cell walls rich in polymer of galactose. Feed by absorption (Osomotrophy). Produce zoospores which possess two unequal dissimilar flagella (one whiplash and other tinsel (Straminipilous), e.g., *Labyrinthula*, *Thraustochytrium*.

You would study the detailed characteristics of the division belonging to Kingdom Fungi in the next unit.

SAQ 4

In the following statements fill in the blank spaces with appropriate word(s):

a) When the entire fungal thallus is converted into one or more reproductive structures the fungus is called ..... .

b) The cellular reproductive units formed by the break-up of a hypha are called ..... .

c) Non-motile sporangiospores are also known as ..... .

d) A zoospore-producing sporangium is called ..... .

e) A fungus is referred to as perfect when it reproduces ..... .

9.9 SUMMARY

In this unit you have learnt that:

- Fungi are eukaryotic, spore-bearing, achlorophyllous organisms exhibiting absorptive mode of nutrition.
- Majority of fungi are aerobes. Light may not be required for their somatic growth. For the induction of reproductive structures exposure to light may be a pre-requisite.
- Fungi live as saprotrophs, biotrophs, nectrotrophs or symbionts. Saprophytic fungi are important decomposers in nature. Parasitic fungi may cause extensive damage to crop plants.
- Fungi show a range of morphological forms. Some of the fungi are unicellular, however, majority of them are multicellular. Slime-moulds are

plasmodial at certain stage of their life cycle. In multicellular fungi, branched mycelium filaments form the somatic body. These mycelia could be aseptate or septate. A septum always delineates a reproductive unit from the somatic mycelium.

- The fungi could be holocarpic or eucarpic. The mode of reproduction in fungi could be vegetative, asexual, sexual or parasexual.
- Various kinds of specialised reproductive structures such as: oidium, chlamydospores, sclerotium, zoosporangium, sporangium, sorocarp and are formed in fungi.
- Organisms traditionally recognised as fungi represent polyphyletic relationship. The kingdom fungi, as identified by Whittaker (1969) is now segregated into: a monophyletic tinsel type (Straminipilous) flagellum bearing fungi – the Straminipila and a protists group comprising divisions of slime moulds and monophyletic kingdom fungi comprising of True Fungi.

9.10 TERMINAL QUESTIONS

1. Name three divisions that comprise kingdom Straminipila. List two genera belonging to each of them. Also mention one character which justifies the creation of a separate Kingdom Straminipila.
2. Describe different methods of plasmogamy in fungi.
3. Match the division of fungi mentioned in Column I to the common names of fungi given in Column II.

Column I	Column II
a) Plasmodiophoromycota	i) True slime-moulds
b) Myxomycota	ii) Slime-net fungi
c) Oomycota	iii) Endoparasitic fungi
d) Labyrinthulomycota	iv) Water moulds

4. Write brief notes on:
   a) Plectenchyma,
   b) Function of fungal cell wall, and
   c) Asexual reproduction in fungi.

9.11 ANSWERS

Self-Assessment Questions

1. a) (i) F; (ii) T; (iii) T; (iv) F.

   b) (i) Chitin; (ii) oxygen; (iii) parasexual; (iv) heterotrophic.

2 a) (i) 6; ii) Myxomycota; iii) 20-30°C; iv) Plasmodiophoromycota.

   b) (1) (ii); 2) (iv); 3) (i); 4) (iii).

3 a) (i), ii) and v) are incorrect. The correct sentences are as follows:

i) Buds produced by yeast when remain attached to each other constitute promycelium;

ii) Aseptate, coenocytic mycelium is characteristic of Zygomycota.

iii) Those fungi which become parasitic under certain conditions are called facultative parasites.

b) 1) (iv); 2) (i); 3) (ii); 4) (iii).

4) a) holocarpic; b) oidia; c) aplanospores; d) zoosporangium; e) sexually.

Terminal Questions

1. The three divisions that comprise kingdom Straminipila are:

   Labyrinthulomycota; Hypochytridiomycota; Oomycota.

   The genera belonging to these divisions are:

   Labyrinthulomycota - *Labyrinthula, Thraustochytrium;*
   Hypochytridiomycota - H*ypochytrium; Rhizomyces;* and

   Oomycota – *Phytophthora*, *Plasmospora*.

   The creation of a separate Kingdom Straminipila is based on the presence of tinsel (straminipilous) flagellum Refer Section: 9.8

2. Planogametic copulation; gametangial copulation; gametangial contact; spermatisation, and somatogamy. Refer Section : 9.7

3. a) iii; b) i; c) iv; d) ii

4. a) Refer Subsection: 9.4.2

   b) Refer Subsection: 9.5.3

   c) Refer Subsection: 9.7.2

9.12 GLOSSARY

Acervulus (plural - acervuli) acervus = heap : A mat of hyphae giving rise to short conidiophores closely packed together forming a bed-like moss.

Amoeba (pl. amoebae) : Unicellular trophic stage of slime-mould often designated as myxamoebae.

Biotroph : An obligate parasite.

Budding (budde = bud) : The production of a small outgrowth from a parent cell; a method of asexual reproduction.

Chitosome (Chitin + Greek Soma = body) : A small cytoplasmic vesicle containing an enzyme chitin synthetase involved in the hyphal tip growth.

Coenocytic (Gr. Koinos = ommon + kytos = a hollow vessel : Non septate nuclei lying in a common matrix (cytoplasm) of mycelium.

Coprophilous (Gr. Kopros = dung + philein = to love)	:	Growing on dung.
Damping off	:	A disease of seedling that causes them to rot at the soil level and fall over.
Dikaryon (di = two + Gr. Karyon = nut, nucleus)	:	A pair of closely associated, sexually compatible nuclei.
Endobiotic (Gr. Endos = inside + bios = life)	:	An organism that lives within its substrate usually the cells of host.
Flagellum (pl. flagella; L. flagellum = whip)	:	A hair-like structure.
Hypha (pl. hyphae; Greek Hyphae = web)	:	The unit of structure of most fungi; a tubular filament.
Mitospore	:	Spore with a nucleus that has been formed by mitosis; an asexual spore (cf. meiospore).
Mycelium (pl. mycelia ; Greek Mykes = mushroom fungus)	:	Mass of hyphae constituting the body (thallus) of a fungus.
Parasite (Gr. Parasitos eating beside another)	:	An organism that lives at the expense of another.
Pycnidium (pl. pycnidia)	:	A hollow fruiting body lined with conidiophores.
Saprobe (Gr. Sapros = rotten + bios = Life)	:	An organism that utilises dead organic matter for food.
Sporodochium (pl. sporodochia; spora = seed + docheion = container)	:	A cushion shaped structure covered with conidiophores.
Synnema (pl. synnemata; *syn* = together + *nema* yarn)	:	A group of conidiophores cemented together and forming an elongated spore-bearing structure.
Septum (pl. septa L. septum = hedge, partition)	:	A cross wall in a hypha that develops centripetally.
Somatic (Gr. Soma = body)	:	The body of an organism as distinguished from its reproductive organs / phase; assimilative phase of fungi; vegetative.
Sorocarp (Gr. Soros = heap + karpos = fruit)	:	The fructification of some slime-moulds where spores are embedded in a matrix without a covering wall.
Thallus (pl. thalii, Gr. Thallos = shoot)	:	A relatively simple plant body devoid of stems, roots, leaves, somatic phase.
Tinsel flagellum	:	A flagellum that bears hairs (mastigonemes) on the flagellar membrane; stramenopilous.

9.14 FURTHER READING

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UNIT 10

FUNGI: TURE–FUNGI

Structure

10.1 Introduction

Objectives

10.2 General Characteristics

Division Chytridiomycota

Division Zygomycota

Division Ascomycota

Division Basidiomycota

Role of Crozier and Clamp Connection in Dikaryotization

10.3 Ecology and Significance

Ecology

Significance

10.4 Life Cycles

Rhizopus

Penicillium

Alternaria

Puccinia

Agaricus

10.5 Summary

10.6 Terminal Questions

10.7 Answers

10.8 Glossary

10.9 Further Reading

10.1 INTRODUCTION

In the previous unit you have learnt the morphology, ecology, reproduction, significance of fungi, especially the various kinds of slime-moulds and the Stramenopiles. This unit describes the biology of the true-fungi, kingdom Fungi, comprising of the divisions: Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota. The study would involve the general characteristics, ecology, significance and life cycles of representative genera of the above-mentioned genera.

Objectives

After studying this unit, you will be able to:

- recognise the monophyletic relationship of the organisms described as true-fungi,
- identify the divisions of true-fungi;
- study the general characteristics of true-fungi;
- appreciate the ecological importance of true-fungi, highlight the significance of true-fungi in industry and human welfare; and
- describe and illustrate the life cycles of *Rhizopus*, *Penicillium*, *Alternaria*, *Puccinia* and *Agaricus*.

10.2 GENERAL CHARACTERISTICS

True-fungi includes the divisions Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota. Some of the characters shared by these divisions are:

Hypha (pl. hyphae; Gr. Hyphe = web) The unit of structure of most fungi, a tubular filament.

Mycelium (pl. mycelia; Gr. Mykes = mushroom, fungus) Mass of hyphae constituting the body (thallus) of a fungus.

- Majority of these fungi are mycelial and often branched; the mycelium could be with or without septa.
- The cell walls of the hyphal cells are made up primarily of chitin and glucan.
- The storage reserve food material is glycogen.
- Except for some stages in the life cycle of chytrids, motility is absent.
- Asexual reproduction is by budding, fragmentation, sporangiospores or conidia.
- Sexual reproduction is through zygospores, ascospores or basidiospores.
- Presence of only large relatively densely distributed macro-secretory vesicles in the apical region of hyphae, prominent in Chytridiomycota and Zygomycota. In hyphal tips of members of Oomycota, they are loosely dispersed.
- Smaller microvesicles in addition to the large macrovesicles are also present in the hyphal tips of members of Ascomycota and Basidiomycota. The combination of smaller and larger vesicles in the tip of hypha is collectively called – "Spitzenkörper".
- Spitzenkörper absent in fungal tips of members of Chytridiomycota and Zygomycota (Fig. 10.1).

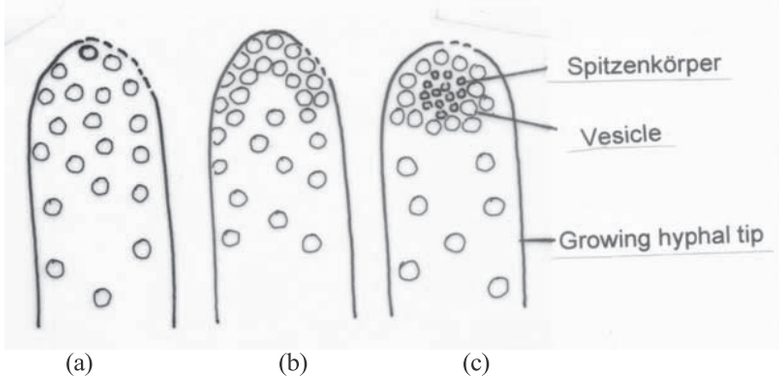


Fig. 10.1: Diagrammatic representation of the arrangement of vesicles in growing hyphal tips of true-fungi. Secretory vesicles are visible in all hyphal tips but the smaller vesicles (chitosomes) are prominent only in Ascomycota and Basidiomycota contributing to Spitzenkörper vesicle cluster (c). Loosely dispersed larger vesicles are prominent in hyphal tips of Oomycota (a), and relatively densely present larger vesicles are characteristic of Zygomycota hyphal tips (b).

The salient features of the four divisions are summarized below.

10.2.1 Division Chytridiomycota

The members are collectively termed as chytrids. They are extremely small in size and can be detected by microscopic examination of cells and tissues colonised by them. The thallus structure exhibits considerable variation. The simplest forms are endobiotic (living entirely within the cells of their host). Others are epibiotic that is living on the surface of host or dead organic matter (Fig. 10.2). Epibiotic forms produce short delicate

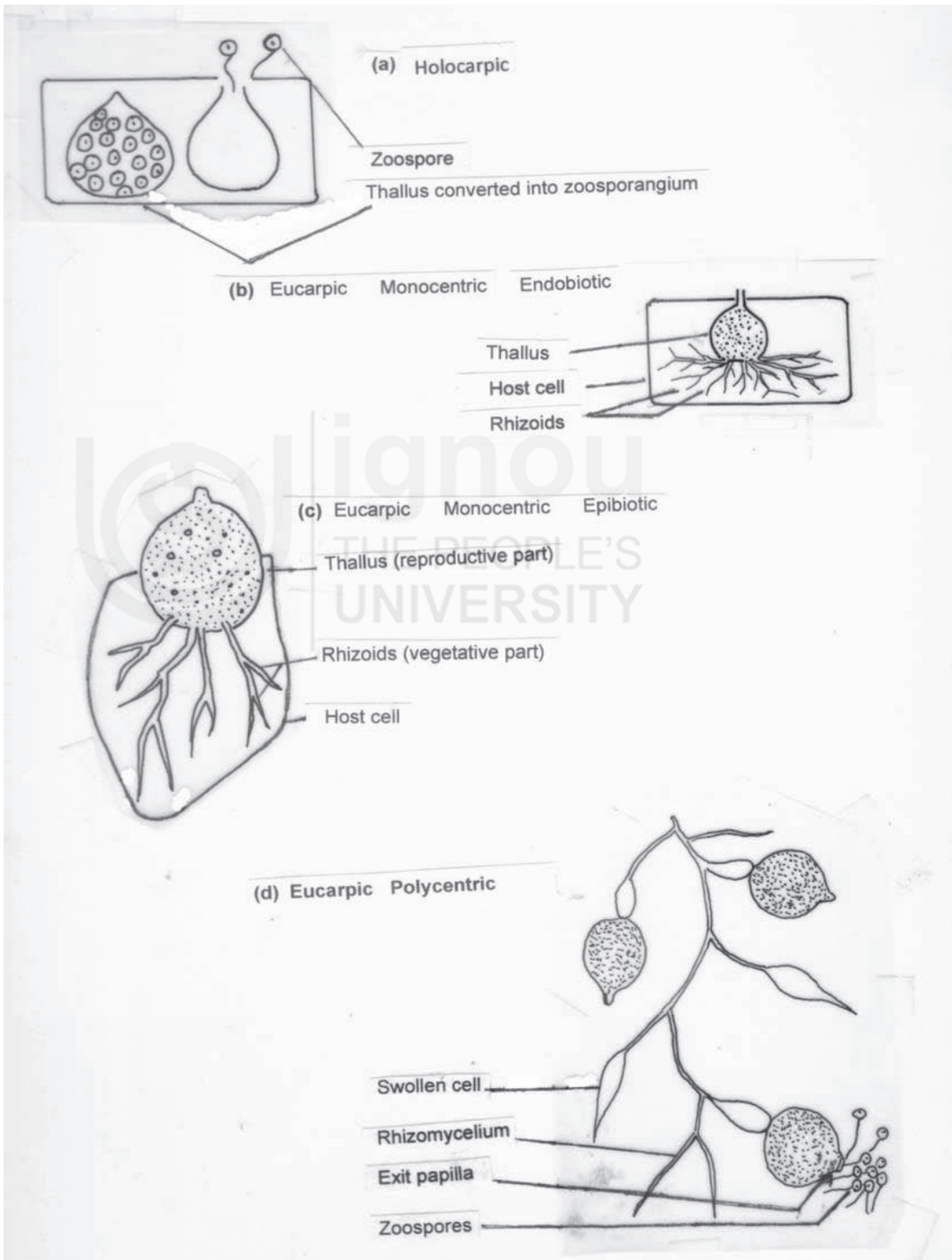


Fig. 10.2 : Types of thallus structure in Chytridiomycota: a) Holocarpic – Endobiotic; b) Eucarpic – Endobiotic; c) Eucarpic – Epibiotic; and d) Epibiotic- Polycentric.

rhizoids for the absorption of nutrients. Asexual reproduction is by means of zoospores. The zoospore possesses a posteriosly placed whiplash type of flagellum. Sexual reproduction takes place by a variety of methods, such as planogametic copulation; gametangial copulation or by somatogamy. Some common chytrids are *Olpidium*, *Synchytrium*, *Chytriomyces*.

10.2.2 Division Zygomycota

These fungi possess coenocytic, aseptate mycelia. The cell organelles within the hyphae exhibit graded distribution. The distal region is rich in endoplasmic reticulum and mitochondria suggesting intense biosynthetic activity and energy generation. The nuclei are observed below this zone. The major portion of hypha that appear empty is actually filled with a large vacuole. Asexual reproduction takes place usually by sporangiospores and aplanospores (Fig. 10.3).

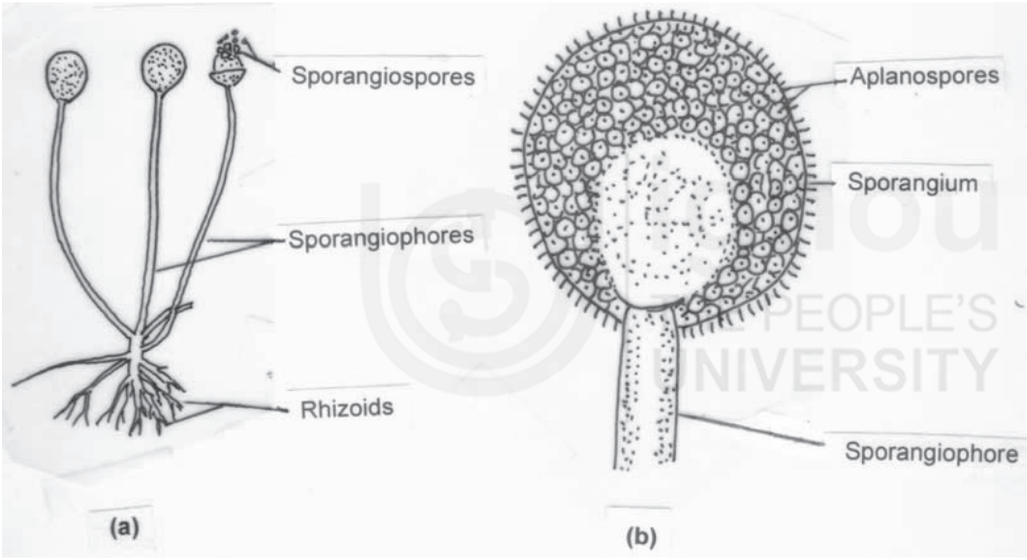


Fig. 10.3 : Zygomycota: a) *Rhizopus*, a common bread mould; b) *Mucor*, asexual reproductive structure.

Sexual reproduction is through fusion of gametangia, resulting in the formation of zygosporangium (pl. zygosporangia). The zygospores are formed within zygosporangium. A complete septum delimits the reproductive structures such as a sporangium or a gametangium from the somatic aseptate mycelium. You would study the life cycle of representative genus, *Rhizopus* in Subsection 10.4.1.

10.2.3 Division Ascomycota

These fungi could be unicellular or posses septate, branched mycelium (pl. mycelia). The septum is incomplete with a prominent central pore, large enough to permit all the protoplasmic contents including nuclei to pass across the adjacent hyphal cell. The development of pore is centripetal that is from periphery to the centre. Specialised, woronin bodies are associated with septal pores. The hyphal cells are multinucleate. Asexual reproduction is by means of

conidia. During sexual reproduction ascospores are produced within sac like structure, ascus (pl. asci). A dikaryotic stage in the life cycle, and plectenchymatous structures are associated with sexual reproduction. Representative life cycles of two genera, *Penicillium* and *Alternaria* are described later in Sub-sections 10.4.2 and 10.4.3.

A large number of Ascomycota are associated with crozier formation during ascus development.

Fig.10.4 exhibits some representative genera and kinds of fruiting bodies. Some of prominent Ascomycota include, *Penicillium*, *Aspergillus*, *Saccharomyces* and *Claviceps*.

10.2.4 Division Basidiomycota

The majority of Basidiomycota members are mycelial. In most Basidiomycota a dolipore septum in mycelial cell wall is prominently present. However, some are yeast like (unicellular) or even dimorphic, i.e., capable of switching between mycelial and yeast like growth, e.g., *Filobasidiella* (*Cryptococcus*) a dangerous human pathogen, causes a fatal disease of brain. In the mycelial forms, three kinds of mycelia may be formed during the life cycle of an organism. These are:

- monokaryotic, haploid **primary mycelium** (somatic mycelium);
- dikaryotic **secondary mycelium** (with each hyphal cell possessing two haploid nuclei belonging to two strains; and
- a diploid nucleus possessing uninucleate tertiary mycelium.

The dikaryotic state in a secondary mycelium is maintained through a specialised kind of cell division involving the formation of a clamp connection. Sexual reproduction involves formation of small to massive fruiting bodies called **basidiocarps**. These produce haploid basidiospores on a specialised structure **basidium** (pl. basidia). Basidiospore germinates to produce haploid, monokaryotic mycelium. Representative life cycles of two genera *Puccinia* and *Agaricus* are described in Sub-sections 10.4.4 and 10.4.5. The common Basidiomycota are: mushrooms, puffballs, stinkhorns, coral fungi, rust and smut fungi (Fig. 10.5).

10.2.5 Role of Crozier and Clamp Connection in Dikaryotization

Dikaryotic mycelia are characteristic of a number of Ascomycota and Basidiomycota. However, there exist prominent differences in the mode, timing and phase in the life of a fungus when this event occurs.

Crozier in Ascomycota

Most Ascomycota except a few, e.g., yeast develop crozier during sexual phase in the life cycle. A *multinucleate ascogonium*, possessing long hyphal branches behave as trichogyne. The spermatia act as male cells. The spermatia are chemically attracted to the trichogyne and unite/fuse with it. The wall between the trichogyne and the spermatium dissolves. The contents of

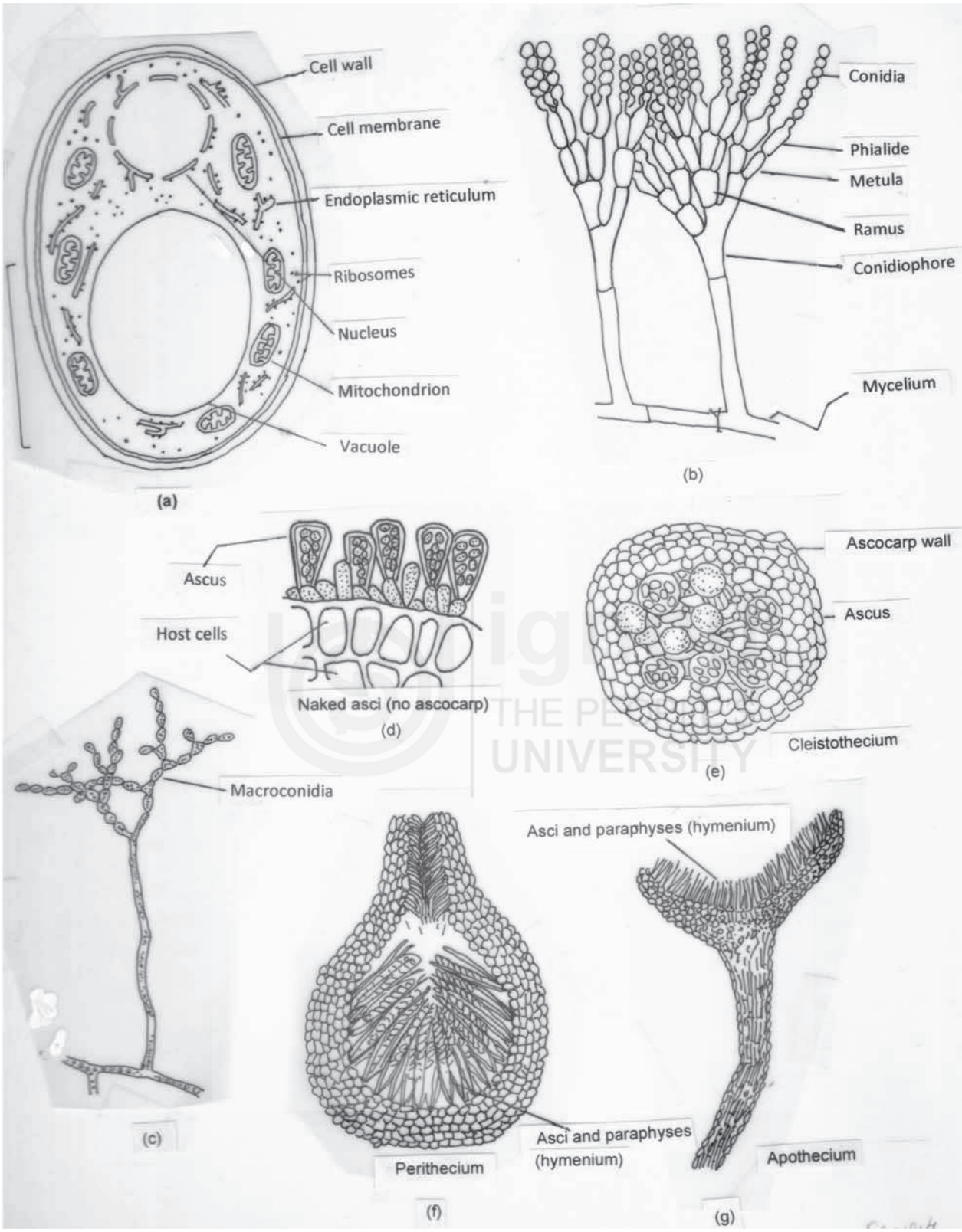


Fig. 10.4 : Some members of Ascomycota: a) Unicellular *Saccharomyces*; b) asexual fruiting bodies of *Penicillium*; c) *Neurospora;* and d)-g) different kinds of sexual fruiting bodies of Ascomycota.

spermatium migrate into the ascogonium. At this stage a specialised cell is formed in a female gametangium, the ascogonium. This cell is called ascogenous hypha. The paired dikaryons migrate into this ascogenous hyphal

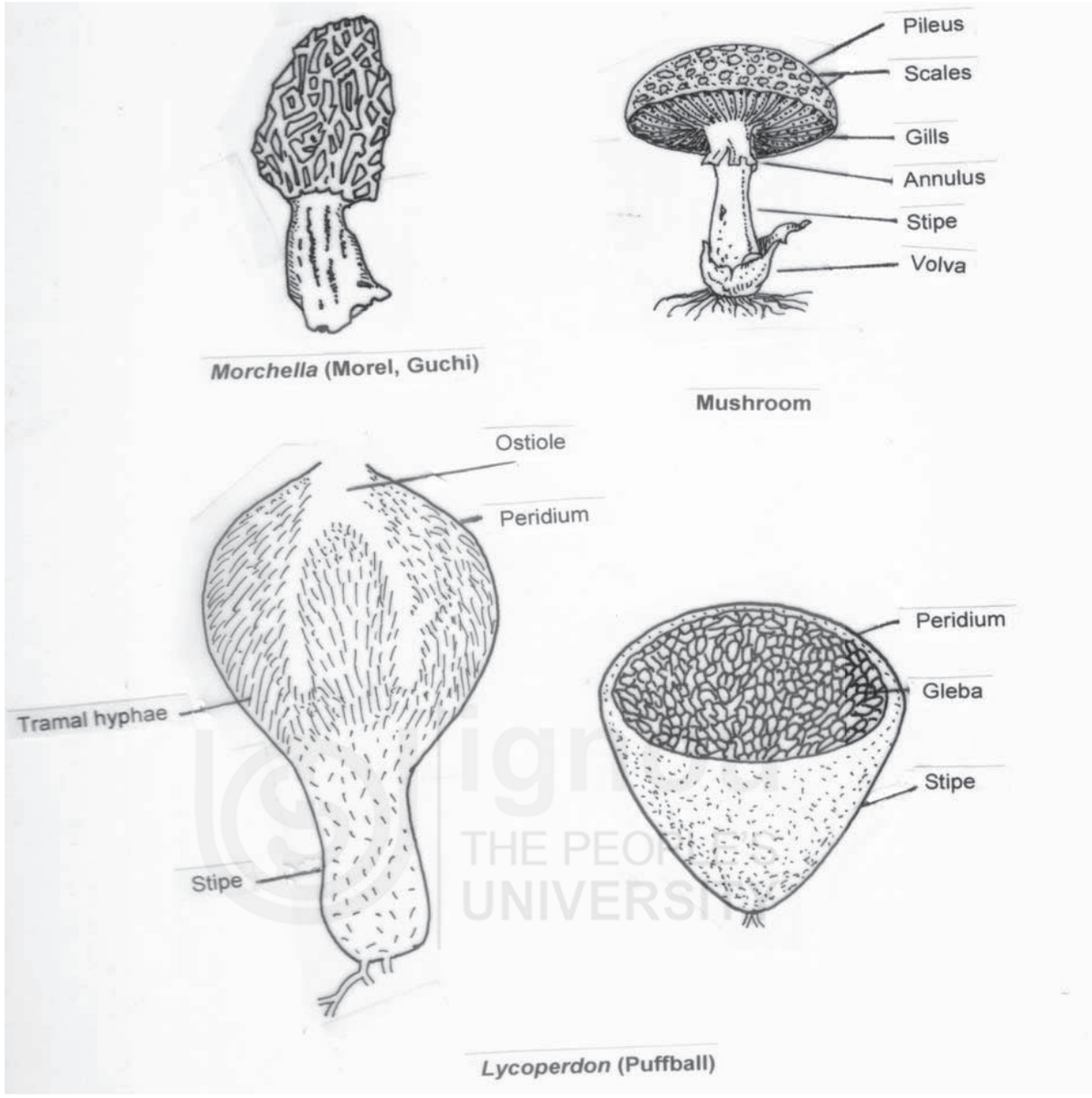


Fig. 10.5: Some common Basidiomycota.

cell. The tip of the ascogenous hypa recurves and forms a hook, the *crozier*. Now, both the dikaryon nuclei divide simultaneously to produce 4 nuclei – two male and two female. The wall deposition results in formation of three cells: upper, penultimate and basal. One nucleus pass on to apical cell and one to the basal. The penultimate cell gets two nuclei, one each of male and female origin. This binucleate cell enlarges and develops into an ascus. Later two nuclei fuse and form a diploid nucleus. This diploid nucleus divides meiotically to produce four haploid nuclei. Further, mitotic divisions may result in formation of eight or more haploid nuclei per ascus. Division of cytoplasm also takes place. Four, eight or more haploid protoplasts are formed which transform into ascospores. The above events are depicted in Fig.10.6.

Clamp Connection in Basidiomycota

The division of dikaryotic hyphal segments is quite unique in most Basidiomycota. The binucleate terminal segment develops a short lateral

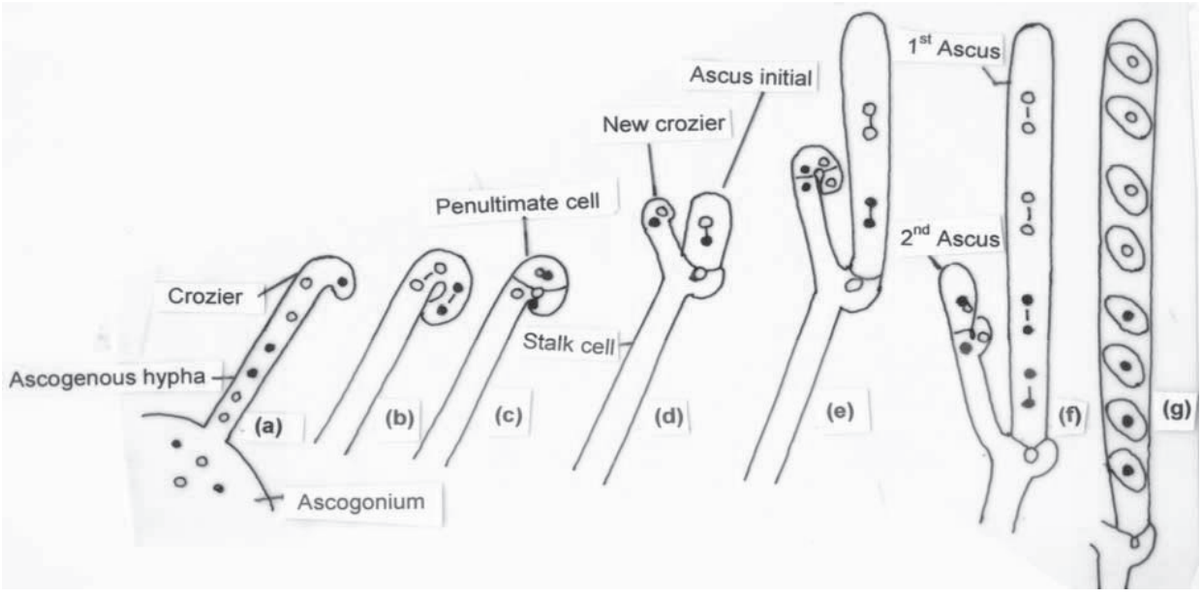


Fig. 10.6: Role of crozier in dikarydization in Ascomycota.

outgrowth. It extends and takes the form of a hook and fuses with the adjacent segment. This is called a clamp-connection. Now one of the nuclei migrates into the hook, other remains in the cell. Subsequently, the two nuclei divide simultaneously. Let us label the nucleus in the hook as 'a' and the one in the cell as 'b'. Following mitotic divisions, the 4 nuclei are a, a^1, b, and b^1. The nuclei a^1, and b^1 migrate to distal/terminal end. The nucleus 'b' remains in sub-apical region and the nucleus 'a' in the hook. Now, the cell-walls are laid down in such a way that a terminal cell is cut off from the proximal end as well as from the hook. The terminal cell gets the nuclei 'a^1' and 'b^1' : The nucleus 'a' migrates from the hook to the sub-terminal cell where nucleus 'b' is already present. The newly formed terminal cell with two nuclei 'a' and 'b' divides again via a new clamp-connection to proliterate secondary mycelium. Rust and smut fungi do not form clamp-connections. These events are depicted in Fig.10.7.

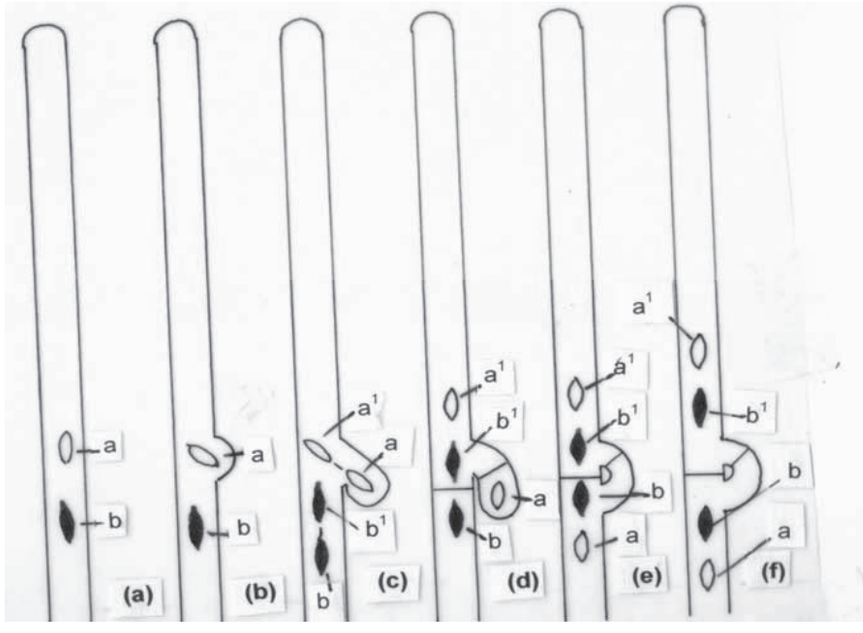


Fig. 10.7: Clamp connection formation in Basidiomycota.

Box 10.1 : The imperfect fungi – class Deuteromycetes.

Recall the terms anamorphs and teleomorphs you have studied in Unit 9. The **teleomorph** is a meiotic morph (form) that produces ascospores or basidiospores, hence is regarded as sexual phase in the life cycle of a fungus. In contrast, the **anamorph** is a mitotic, asexual morph in the life cycle. These are also referred to as **perfect** (sexual) or **imperfect** (asexual) phases in the life cycle of an organism respectively.There are a large number of fungi known only by their anamorphs. They reproduce only by asexual, conidial phase, i.e., their sexual phases are still unknown. In such a situation, the anamorphic phase represents **holomorph** [phase(s) representing a fungus in all its expressions]. Such anamorphs are placed by many mycologists in a separate class **Deuteromycetes** (Fungi Imperfecti.) Whenever, a teleomorph of a fungus is found associated with or to such an anamorph, then they are accordingly classified as Ascomycota or Basidiomycota, depending on the kind of sexual fruiting bodies produced by them. For example:·

- Conidial anamorph *Aspergillus* is associated with ascus forming teleomorph *Eurotium*.
- Condial anamorph *Penicillium* is associated with ascus forming teleomorph *Talaromyces*.
- Conidial anamorph *Haplotrichum* is associated with basidia forming teleomorph *Botryobasidium*.
- Conidial anamorph *Spiniger* is associated with basidia forming teleomorph *Heterobasidium*.

SAQ 1

Choose the correct alternative mentioned in the brackets:

a) Spitzenkörper is absent in (Zygomycota / Ascomycota).

b) The fungi that can be visualised by microscopic examinations of the cells and tissues colonized by them are (moulds / chytrids).

c) Dolipore septum is observed in the mycelia of fungi belonging to (Ascomycota / Basidiomycota).

d) Secondary mycelia in Basidiomycota are (monokaryotic / dikaryotic).

SAQ 2

In the following statements fill in the blank spaces with appropriate word(s):

a) *Saccharomyces* belongs to Division ..... .

b) Asexual reproductive spores in Zygomycota are called ..... .

c) ..... is the only division of true-fungi that exhibit motility.

d) The cell wall of true-fungi are made up of chitin and ..... .

e) Storage reserve food material in true-fungi is ..... .

10.3 ECOLOGY AND SIGNIFICANCE

True-fungi constitutes a very large group of organisms found in almost every ecological niche. These fungi are extremely valuable as decomposers and producers of a large number of secondary metabolites. They are also a source of delicacies as well as cause of a number of diseases in plants, animals and humans. In the following two Sub-sections you would study their ecology and importance to human beings.

10.3.1 Ecology

Let us now study the ecology of four divisions of true-fungi.

Chytridiomycota

Many chytrids are endobiotic while others are saprobes. They occur in both fresh and marine waters as well as on soil. A few anaerobic species inhabit the guts of herbivores. Being very small in size these can be detected only by microscopic examination of cells/tissues of plants/animals and dead organic matter.

Many chytrids parasitise vascular plants, mosses and planktons. They also parasitise nematodes, tardigrades, rotifers, mosquitos, midges, beetles and many others. They also parasitize VAM fungi, Ascomycota and Basidiomycota members. *Zoophagus insidians* occurs in activated sludge in sewage treatment plants.

Zygomycota

Organisms belonging to Division Zygomycota as a group can be isolated from a variety of substrates such as soil, dung, fruits, flowers, stored grains, fleshy plant organs, mushrooms, vertebrates and invertebrates. Nutritionally, they are primarily saprobes. They can be facultative weak parasites. Members of order Zoopogales are obligate parasites. Members of order Endogonales and Glomerales are mycorrhizal.

Ascomycota

Members of Division Ascomycota inhabit a broad range of habitats. They live on dung, bark, wood, leaves, in fresh water or rarely in marine habitats. They also form mutualistic relationship with blue green and green algae in lichens. They occur as endophytic mycorrhizae. *Chaetomium*, *Trichoderma* break down cellulosic fabrics. Species of *Fusarium*, *Metarhizium* exhibit potential insecticidal properties.

Basidiomycota

Organisms belonging to Division Basidiomycota are found from Arctic to Tropical environments. Primarily they inhabit wooded areas, swamps, lawns, and pastures. They occur on soils as well as dead leaves, wood, and dung as saprobes.

The true-fungi play a very important role ecologically as decomposers in forest ecosystem. They also constitute a substantial biomass of forests. They help recycle most essential nutrients.

10.3.2 Significance

Organisms representing True-fungi are very significant to mankind as food providers; food spoilers; fermenters; source of enzymes; antibiotics, drugs and hallucinogens. They are pathogens of plants, animals and human beings. They play an important symbiotic role in mycorrhizae and lichens.

Fungi as source of food

About 2000 species of fungi suitable for human consumption have been reported from all over the world. These include *Agaricus campestris* (field mushroom); *A. bisporus* (white button mushroom); *A. arvensis*; *A. macrosporous*; *A. sylvaticus* and *A. rodmani*. Other mushrooms which are regarded as delicacies of table are: *Pleurotus*; *Lentinula*; *Morchella*; *Clavaria*. A number of species belonging to *Penicillium* help ripen cheese, for example, *P. roqueforti* (Roque-fort cheese) and *P. camemberti* (camembert cheese). Other species of genus *Penicillium* help ripen Danish blue cheese, Italian cheese; Gorgonzola cheese.

Fungi as food spoilers

Fungi are an important cause of spoilage of food items. Table 10.1 lists some of them:

Table 10.1: Some Examples of Fungi Associated with Spoilage of Food Items

Name of Fungus	Food Items
Aspergillus flavus, *A. parasiticus*	Fruits, vegetables, stored grains, peanuts
Claviceps purpurea	Wheat, barley, rye, oat, grains
Rhizopus stolonifer	Damp bread, strawberry, sweet potato
Rhizopus stolonifer	Softening of canned fruits
Byssoclamys fulva	Canned fruit and fruit juices
Mucor racemosus	Stored fruits
Gilbertella persicaria	Stored peaches and tomatoes
Alternaria spp.	Tomatoes in field

Fungi as fermenters

A number of fungi help fermentation process to produce high quality products including beverages and industrial products (Table 10.2).

Table 10.2: Foods and Beverages Produced from Fungi

Name of Fungi	Product
Saccharomyces cerevisiae	Baker's Yeast, Wine
S. carisbergenis	Lager Beer
S. rouxii	Soy Sauce
Candida milleri	Sour French Bread
Aspergillus oryzae	Sake (Rice-starch hydrolysis)
Rhizopus sp.	Tempeh
Mucor sp.	Sufu (Soybean curd)
Monascus purpureus	Ang kak (Red rice)
Saccharomyces cerevisiae	Ethanol (from glucose)
Kluyveromyces tragilis	Ethanol (from lactose)
Aspergillus niger	Citric acid
Rhizopus stolonifer	Fumaric acid
Rhizopus sp.	Citric acid

Fungal enzymes useful in industry

Many fungi are sources of enzymes that are helpful in food industry. Some fungal sources, their applications, and enzymes are listed in Table 10.3.

Table 10.3: Some Fungal Enzymes Useful in Food Industry

Enzyme	Source	Application
Amylases	*Aspergillus, Rhizopus*	Conversion of starch to fermentable components in baking, brewing and syrup manufacture. Clarification of fruit juices, Scrap candy recovery, vegetable canning
Catalase	*Aspergillus*	Decomposition of H_2O_2 in dairy and egg products
α-Glucosidase (maltase)	*Saccharomyces uvarum*	Conversion of maltose to glucose in dairy products
Glucose oxidase	*Aspergillus Penicillium*	Conversion of glucose to gluconic acid Removal of oxygen from juices
Invertase	*Saccharomyces cerevisiae, Candida utilis*	Conversion of sucrose to glucose and fructose used in production of artificial honey
Lipase	*Aspergillus, Rhizopus*, *Pencillium candida*	Conversion of fat to glycerol and fatty acids. Flavor production in cheese. Removal of egg yolk from egg white

Fungi as Plant Pathogens

Fungi are the principal cause of a number of diseases in plants, especially the ones which are economically important for human consumption. Some such important plant diseases and their causative fungal organisms are given in the Table 10.4.

Table 10.4: Some Important Fungal Diseases of Plants

Fungal Diseases	Causative Fungi
Black wart of potato	*Synchytrium endobioticum*
Club root of cabbages	*Olpidium brassicae*
Ergot of bajra	*Claviceps microcephala*
Frog eyespot of tobacco	*Cercospora nicotianae*
Loose smut of wheat	*Ustilago tritici*
Loose smut of sorghum	*Tolyposporium filliferum*
Powdery mildew of pea	*Erysiphe polygonii*
Rust of linseed	*Melampsora lini*
Stripe of wheat	*Helminthosporium sativum*
Tikka disease of groundnut	*Cercospora arachidicola*
Chestnut blight	*Cryphonectria parasitica*

You would learn the disease cycle of pathogenic fungi *Alternaria* and *Puccinia* in Subsections 10.4.3 and 10.4.4.

Plant disease management requires management of pathogen, host and environment. Management of the pathogen involves the practices directed to reduce, eradicate and prevent infection. Management of host involves the practices directed to improve plant vigour and induce resistance through nutrition, induction of genetic resistance through breeding and providing protection against attack by chemical means. Management of environment involves water management, soil management, and crop management.

Fungal Antibiotics, Drugs and Hallucinogens

In 1929, Sir Alexander Fleming first established the role of fungi in producing antibiotic substances. He extracted the antibiotic penicillin from *Penicillium notatum.* Penicillin is an organic substance lethal to microbes. It is far more effective than ordinary drugs and germicides. It was the first antibiotic to be widely used during Second World War.

Penicillin has tremendous industrial applications for the production of antibiotics. Two species are most common in this regard. *P. chrysogenum* for penicillin and *P. griseofulvium* for griseofulvin. It is worth mentioning here that the species *P. notatum* from which penicillin was first discovered is not commonly used for manufacturing penicillin anymore. Today more than 1000 antibiotics are produced from about six genera of fungi. *Cephalosporium acremonium* produces potent antibiotic cephalosporin capable of acting on a wide variety of pathogenic bacteria.

One well-known non-antibiotic use of microbial seconday metabolites relates to the ergot alkaloids. *Claviceps purpurea* produces sclerotia in the ovaries of

the flowers of grasses such as rye. The sclerotium is called the ergot of rye. Ergot is used in veterinary and human medicine. It contains a mixture of alkaloids, that cause rapid and powerful contractions of the uterus. The medicine is thus used to control bleeding during childbirth.

Ergot is a rich source of many bioactive substances used by pharmacologists as medicines. Synthetic derivatives of ergot alkaloids are used against nervous disorders, migraine, parkinsonism, and senile dementia.

The giant puffball, *Clavatia* contains an anticancer substance called calvacin.

One of the most powerful hallucinogens, lysergic acid diethylamide (LSD) produces psychedelic effects in the human brain. Many mushrooms *Conocybe, Psilocybe* and *Stropharia* from Mexico produce similar hallucinogens – known as psilocin and psilocybin.

Poisonous mushrooms are also important sources of drugs used for treating human ailments. Muscarine (from *Amanita muscaria)* greatly helped in our understanding of transmission of nerve impulses.

Mushroom, *Amanita, Galerina, Gyromitra* produce toxins that cause cellular distraction. Toxins from *Coprinus*, *Inocybe* and *Clitocybe* affect autonomous nervous system. Central nervous system is affected by toxins released by *Amanita*, *Psilocybe*. Toxins from several mushrooms cause gastrointestinal irritations. However, *Globiformes graveolens* produce air freshners.

Fungal Diseases in Humans and Animals

You are familiar with the devastating effects of fungal diseases of plants. Fungi cause many diseases in animals and human beings also. In human beings, fungi can cause mycoses, allergies and toxicoses.

Mycoses are diseases resulting from the invasion of living cells by fungi.

Allergies are diseases resulting from the development of hypersensitivity to fungal antigens.

Toxicoses are illnesses due to ingesting of toxic fungal metabolites formed in the food due to fungi. Besides producing toxins, the fungi can also induce host plants to produce toxic substances.

Mycotoxins are secondary metabolities produced by fungi and can cause unnatural changes in the host.

The systemic or deep mycoses are often fatal or serious. The organisms invade subcutaneous tissues or the lungs, from where they get established and produce the disease. Many of them are air-borne and enter the body through the respiratory tract. The symptoms of some of these systemic mycoses resemble tuberculosis or other diseases. Therefore, accurate diagnosis of the disease is essential for proper treatment. Some of the commonest diseases caused by dermatophytes in mammals are ringworm, sporotrichosis, lumpy wool and facial eczema.

To the unaided eye ringworm appears in the form of patches of dry, raised, crusty skin covered with scales or scabs.

There are contagious skin infections, variously named Herpes, Dermatomycosis, Tinea and many others. They are caused by the growth of fungi which live either upon the surface of the skin or in the hair of the animals. Ringworm and favus are caused by parasitic fungi *Trichophyton* and *Microsporum. Pneumocystis schenckii* causes virulent pneumonia in humans.

Favus affects dogs, cats, rats, mice, rabbits and sometimes fowl. It is characterised by the formation of scales which have a depression in their centre, giving an appearance suggestive of a favus (honeycomb).

Facil eczema in sheep and cattle is seen commonly in New Zealand and Australia. It is caused by the fungus *Pithomyces chartarum*. It produces a poisonous substance, "sporidismin", which is actually responsible for the disease.

Alternaria, Aspergillus, Curvularia, Fusarium are few fungal genera which are found in air and are allergenic to human beings. *Alternaria alternata*, *A. infectoria*, *A. longipes* are rare but opportunistic human pathogens. They are associated with cutinous tissues of ear, bones, eyes, nose and urinary tract.

Fungi in Bio Control

Many types of insects, aphids and other animals also attack the crop plants. They not only damage the plants physically by cutting, eating and sucking the sap but also carry disease-causing bacteria, viruses and fungal spores. Therefore it is necessary to control insect populations to save the crops. This can be achieved by using entomopathogens and bioinsecticides. A chytrid, *Coelomyces*, parasitizes mosquito larvae. It could be valuable as a biological control agent.

Entomopathogens may either cause diseases in target insects or may kill them either by themselves or in combination with chemical insecticides. It is known that over 500 species of fungi (Entomophthorales) can infect and kill various insects. These fungi constitute a powerful alternative method of biologically controlling various insects without using chemicals, which are harmful to man, domestic animals and environment.

Microbial insecticides generally produce no adverse environmental or health effects. In USA, mites, beetles, and caterpillars, pests of crops, stored grains and other products have been successfully controlled by means of *Entomophthora virulenta* and *Hirsutella thompsonii*. Other important examples of fungal entomopathogens include chytrid and *Lagenidium* (Oomycetes) parasitizing mosquitos. *Entomophthora* parasitizes aphids and caterpillars, and *Verticillium* is pathogenic to aphids and white flies.

Mycorrhizal Fungi

The distribution of fungi is generally confined to the top 6 inch layer of soil. Soil contains a large array of inorganic and organic substances and microbes, particularly fungi involved in biological transformation of various substances. Moulds are quite important because they can decompose cellulose, proteins and other complex organic substances. A specialised habitat in soil is constituted by the **rhizosphere** (the immediate vicinity of plant roots). This is a region of high microbial activity. The microorganisms associated with rhizosphere represent an example of mutualistic interaction because large

amounts of sugars, amino acids and derivatives of nucleic acids that serve as food for fungi and other organisms are excreted by roots. The rhizosphere organisms not only degrade complex substrates, but provide nutrients and sometimes also produce certain plant growth hormones. You would read more about mycorrhizal fungi in the next unit.

SAQ 3

Match the fungi mentioned in the column I with the habitat mentioned in the column II:

	Column I		Column II
a)	Chytrid	i)	Activated Sludge
b)	*Rhizopus*	ii)	Lawns
c)	Mushroom	iii)	Guts of herbivores
d)	*Zoophagus*	iv)	Stale bread

SAQ 4

Choose the correct alternative mentioned in the brackets:

a) *Rhizopus* is used to obtained enzyme (amylase / catalase).

b) Loose-smut of wheat is caused by the pathogen (*Puccinia* / *Ustilago*).

c) Anti-cancer bioactive substance is obtained from (*Clavatia* / *Psilocybe*).

d) *Coleomyces* is a (symbiotic / parasitic) fungi.

10.4 LIFE CYCLES

Let us now study the life cycles of some common fungi.

10.4.1 *Rhizopus*

Rhizopus is a member of Division Zygomycota. It is also called bread mould since it is frequently found growing on stale bread. It is a saprophytic fungus. It also grows on decaying fruits, vegetables and other food materials.

Somatic Structure

The mycelium is a white cotton-like fluffy mass with numerous, slender, branched hyphae. The somatic mycelium has two types of hypae: i) rhizoidal and ii) stolons (Fig. 10.8 a).

The rhizoidal hyphae are a cluster of brown, slender and branched rooting hyphae which arise from the lower surface of the stolon at certain points which are the apparent nodal points. These hyphae help in anchorage and in the absorption of water and nourishment from the substratum.

The aerial hyphae which grow horizontally over the surface of the substratum are called stolons. These hyphae are comparatively large, and slightly arched. The stolons grow rapidly in all directions, completely filling the surface of the substratum.

Asexual Reproduction

Rhizopus reproduces asexually by multinucleate, non-motile spores which are produced in small, round, black sporangia. These sporangia are borne terminally, and singly on unbranched sporangiophores. These sporangiophores arise from the nodal regions, opposite to the rhizoidal hyphae in a cluster (Fig. 10.8 b). A mature sporangium is differentiated into two regions, a central less dense, vacuolated region with fewer nuclei called columella and a peripheral dense region with many nuclei called sporiferous region. The protoplast in the columella is continuous with that of the sporangiophore.

The sporiferous region undergoes cleavage to form a number of multinucleate segments. Each of these segments round off and secrete walls around them to become a sporangiospore. It is a unicellular, multinucleate, non-motile aplanospore, globose or oval in shape. As the spores mature the sporangium bursts open liberating the spore mass. A part of the wall remains as a collar-like fringe at the base of the sporangium.

The spores are dispersed away by wind. Falling on a suitable substratum, under favourable conditions a spore germinates producing a short germ tube which grows further and branches profusely to produce three types of hyphae.

Under unfavourable conditions *Rhizopus* produces chlamydospores. As you have learnt they are thick-walled spores with accumulated reserve food. They are produced intercalarily. They help to tide over unfavourable conditions during which time the mycelium perishes. With the return of favourable conditions they germinate and produce normal mycelium.

Sexual Reproduction

Towards the end of the growing season *Rhizopus* reproduces sexually. Sexual reproduction is of conjugation type (Fig. 10.8b). Here the protoplasts of two gametangia fuse. Such an union of protoplasts is called gametangial copulation. Some species of *Rhizopus* are homothallic while others are heterothallic (Box 10.2). In heterothallic species the mycelia belong to one plus and other minus strain.

During sexual reproduction the hyphae of the two mating types (+ and –) called zygophores are attracted towards each other. They produce copulating branches called **progametangia** which meet at their tips. The tips of the progametangia enlarge due to accumulation of cytoplasm and nuclei, and are cut off from the basal portion by cross walls. The sub-terminal portion is called **suspensor.** The entire gametangium transforms into an aplanogamete. The two gametangia may be of the same size or one of them slightly smaller than the other.

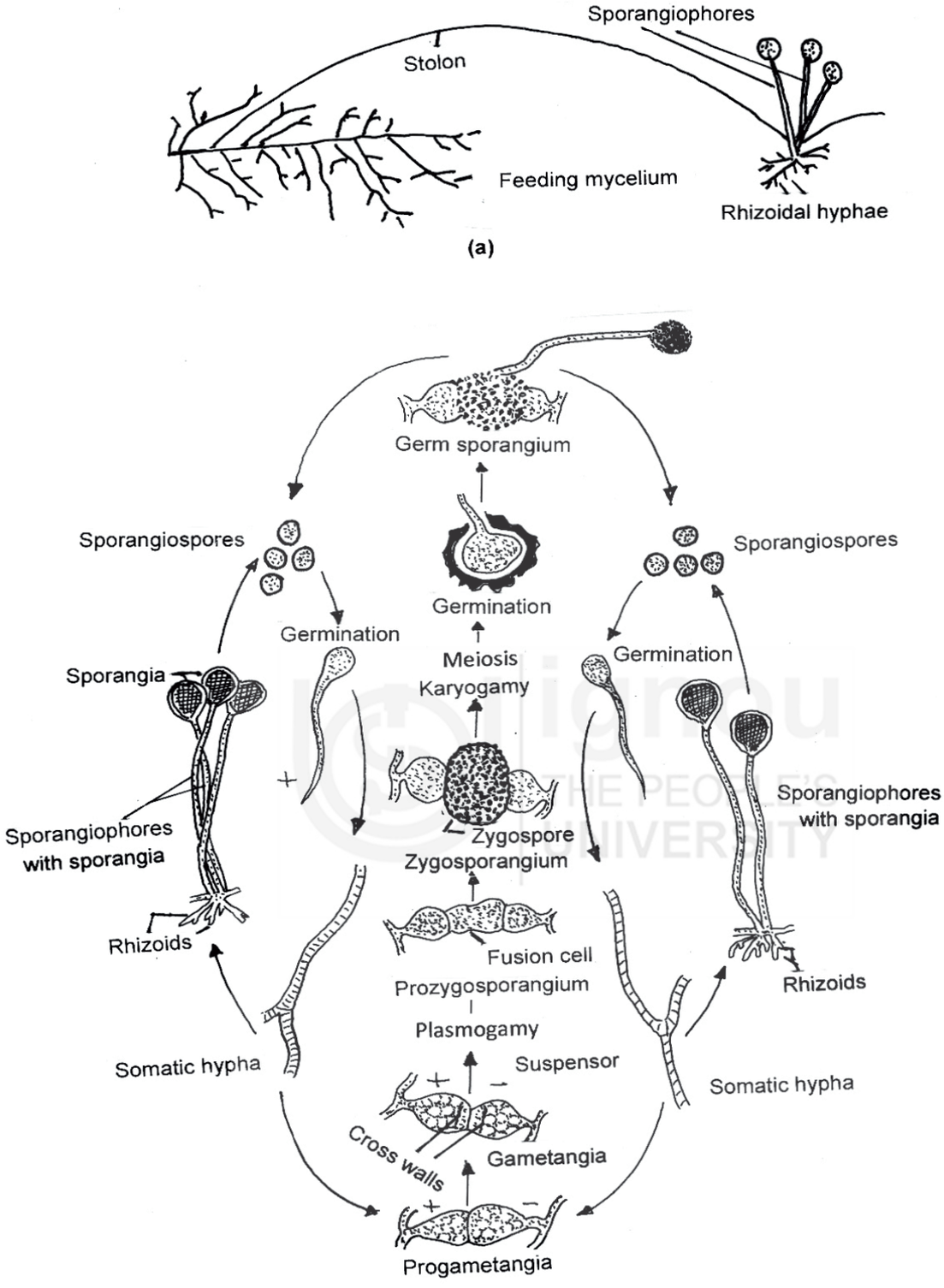


Fig. 10.8 : ***Rhizopus stolonifer*****: a) Three kinds of hyphae of the mycelium, note sporangiophores at the point of rhizoidal hyphae; b) Life cycle.**

When the gametangia mature the intervening walls dissolve and the two gametes and their nuclei fuse producing a zygospore.The zygospore increases in size and secretes a thick two-layered wall around it. The outer layer is dark and warty. It is called **exine** or **exospore**. The inner layer is thick and is called **intine** or **endospore**. As the zygospore increases in size the wall of the fusion cell containing the zygospore ruptures and it is set free.

Box 10.2: Heterothallism.

Rhizopus exhibits heterothallism wherein the mycelia of a single species are morphologically similar but physiologically different. There is no apparent distinction between male and female mycelia except in their sexual behaviour. Such a distinction is designated by the terms plus and minus. This was first discovered by Blakeslee in 1904. This is regarded as the first indication of the origin of dioecious condition of sexual phase in an organism.

Prior to germination of the zygospore, the diploid nuclei divide meiotically producing numerous haploid nuclei. During meiosis segregation of strains takes place. The zygospore during germination absorbs water and swells. As a result the outer wall - exine breaks open. The inner wall intine with the inner contents grows out as a germ tube or promycelium. The promycelium is of limited growth and produces a terminal sporangium. It is called **zygosporangium** or germ sporangium. Inside the sporangium numerous, non-motile germ spores called meiospores are produced. They are liberated at maturity which develop into new mycelia.

Such a sexual cycle is called **haplontic** characterised by zygotic meiosis and haploid mycelium.

10.4.2 *Penicillium*

Penicillium (Fig. 10.9) belongs to Division Ascomycota. It is commonly called green mould or blue mould. *Penicillium* has more than 200 species. It occurs as saprophyte in soil and air and is a potentially pathogenic fungus. You may refer previous Sub-section 10.3.2 for the ecology and significance of *Penicillium*. The genus *Penicillium* is subdivided into many sub-genera *Verticillium* is correlated to teleomorph *Talaromyces*. The sub-genera *Penicillium* has no known teleomorph and is reported only in phialidic anamorphic state.

Somatic Structure

The mycelium consists of well developed profusely branched, septate and hyaline hyphae. The hyphae cells are multinucleate.

Asexual Reproduction

Penicillium reproduces asexually by the formation of conidia. These conidia are globose to ovoid and under the microscope resemble glass beads. These could be greenish, bluish or yellow. The conidia readily germinate by germ tubes to form mycelia. The conidia formation is preceded by the development of simple, long, erect conidiophores from prostrate mycelia. These conidiophores branch about two-thirds of the way to tip. Such conidiophores are termed as penicillus (pl. penicillin = small brush). From the tip of the conidiophores arise several smaller branches (metulae). The metulae in turn divide again to form sterigmata (Fig. 10.9). These sterigmata are bottle shaped and are called phialides. The phialides cut off conidia in long chains. The branching of conidiophore may be symmetrical or asymmetrical, or broom-like.

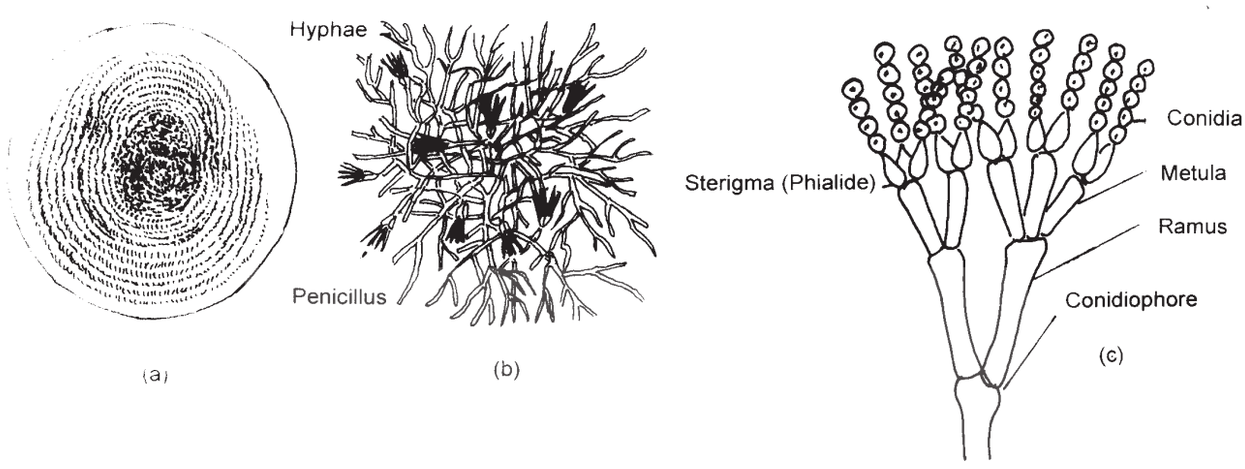


Fig. 10.9 : *Pencillium*. a) A colony; b) mycelia with penicilli; and c) an asexual fruiting body.

Sexual Reproduction

The sexual state of most species of *Penicillium* has not been clearly worked out. However, Penicillium-type conidial stage has been recognised in two genera of the family Eurotiaceae. The genera are *Eupenicillium* (synonym: *Carpenteles*) and *Talaromyces* (Fig.10.10). The sexual reproduction as reported in *Talaromyces flavus* is described as under:

Talaromyces flavus has uni-nucleate hyphae that bear club-shaped uninucleate ascogonia (singl. ascogonium). An antheridium originates as a uninucleate branch of a separate hypha. The antheridium grows spirally around the ascogonium at the point where the tip of the thin antheridium touches the ascogonium, the walls dissolve. It is followed by plasmogamy, resulting in the formation of binucleate ascogonial cell. Such ascogonial cells become septate and branch profusely. These branches develop into ascogenous hyphae. Karyogamy takes place in the ascus mother cell the asci develop in chains. Simultaneously the somatic hyphae envelope the sexual apparatus. The pear-shaped or globose asci produce ascospores after meiosis. Soon after ascospores are formed the spiny ascospores are released into a fruiting body called the cleistothecium. The details of origin of paired nuclei in ascogonial cells, nuclear pairing are unclear in *Talaromyces*. For a generalised overview of sexual reproduction and the role of crozier in dikaryotization in Ascomycota you may refer to Fig. 10.6. Each of the ascspores germinates by germ-tube and grows into a mycelium.

10.4.3 *Alternaria*

A vast number of species belonging to class Ascomycetes are known by their asexual stages only. A practice has been to place such taxa in the artificial group called fungi Imperfecti (refer Box 10.1). These are also referred to as asexual Ascomycetes. The genus *Alternaria* is an example of fungi imperfecti. It represents an anamorph, belonging to class Loculoascomycetes which has not been connected to any teleomorph (sexual phase). It is also an example of mitosporic fungi.

Mitosporic – Organisms which reproduce by sexual spores.

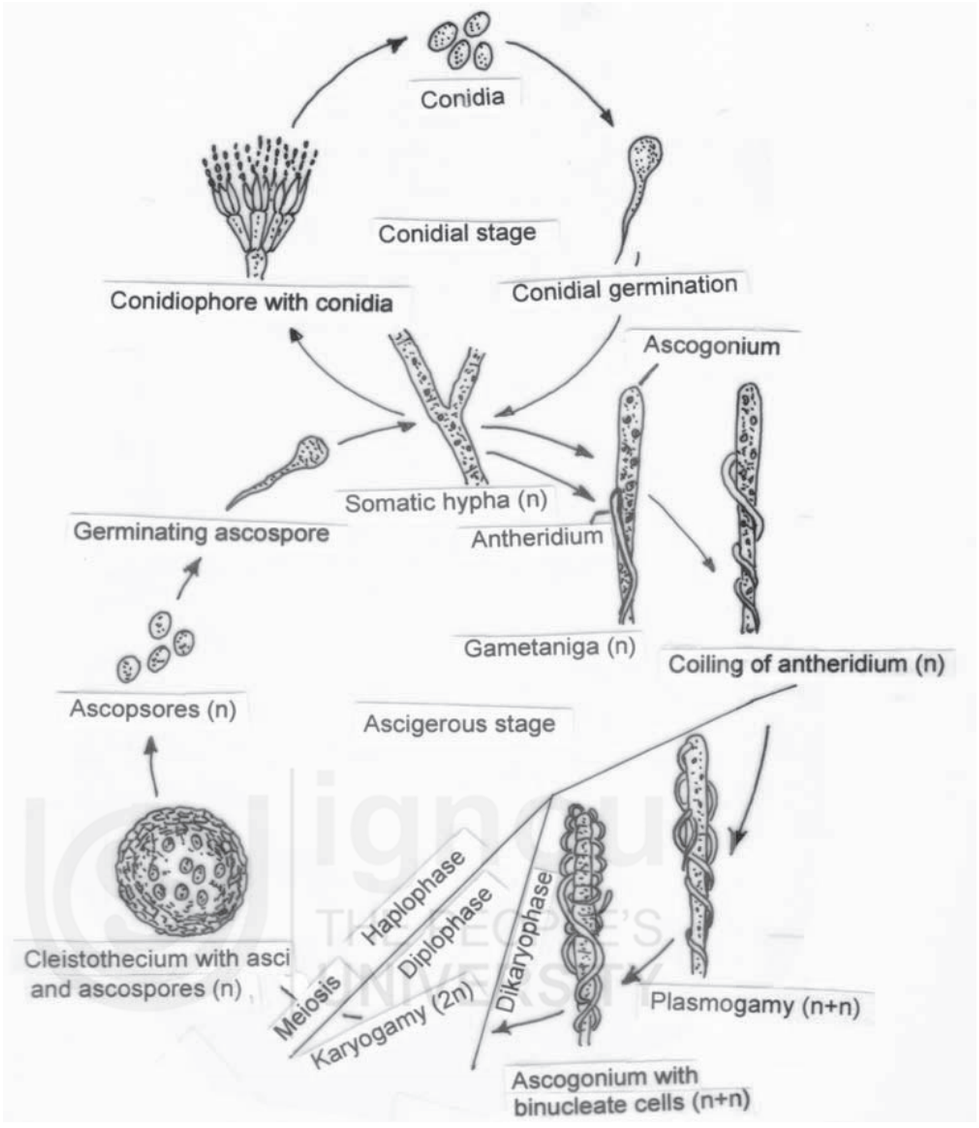


Fig. 10.10: Life cycle of *Talaromyces vermiculatus* (*Penicillium vermiculatum*).

Alternaria conidia (Fig. 10.11) are more common in outdoors than in indoors. There are about 50 species of *Alternaria*. *Alternaria tenuis* is an opportunistic saprobe on all kinds of senescent materials. You may refer to Section 10.3 for the ecology and significance of the genus *Alternaria*.

Somatic Structure

The hyphae are dark, septate, and branched. The cells are multinucleate and the septa are perforated, permitting the streaming of cytoplasm and the migration of nuclei from one cell to another.

Asexual Reproduction

Alternaria reproduces through mitospores (derived by mitosis). These are called conidia (singl. conidium). The conidium borne acropetally, is an non-motile asexual spore formed at the tip of mycelial filament. The conidium has 2-layered cell wall. The outer one is melanized and possesses a pore. The hyaline, inner cell wall expands through, the pore and constitutes the primary cell wall of a new conidium. Later, this new conidium also gets an outer cell

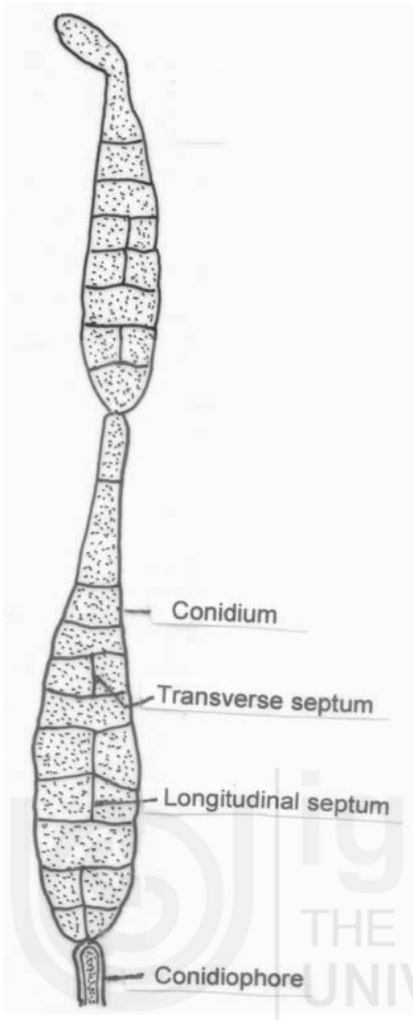


Fig. 10.11: Multicellular conidia of *Alternaria*.

wall. Thus, a conidium can produce a new conidium forming a chain of conidia at the tip of condiophore that is the mycelium that produces conidia. A conidium possesses both transverse as well as longitudinal septa. Such septa are incomplete. The pores within the septa permit the flow of protoplasmic contents across the condium. The conidium possesses a long beak in *A. solani* and *A. brassicae*. This beak helps in air-dispersal of conidia.

Despite the absence of a formal evidence of sexual reproduction in many species of *Alternaria*, mating type idiomorphs have been isolated in *A. brassicae, A. brassicola and A. tenuissima*.

Early blight of potato – Disease Cycle

Causal pathogen: *Alternaria solani*

Host: *Solanum tuberosum*

The source of primary inoculum for infection are the conidia. These conidia are viable for a considerable length of time in soil and air. Generally, they lie within the soil released from the infected leaves of previous crop.

These conidia germinate, preferring temperature range of 28°- 30°C. They penetrate new host through the stomatal pores or epidermis in the leaves of

the host. The period of incubation is relatively short. Infection spots on the leaves become visible within 48-72 hrs of infection. A new crop of conidia are produced within next 4 days. The conidia gets released into air and get dispersed by air currents.

Symptoms: The disease (Fig. 10.12) can be recognised by the appearance of 'spots' on the leaflets. These spots are brownish-black; ovate to angular in outline, and 3-4 mm in diameter. The infection makes the leaves senescent. The lower leaflets are attacked first. The affected leaves show ragged, irregular margins. Sometimes, infection tissue gets blighted due to necrosis. Later, tuber also show circular to irregular slightly sunken lesions.

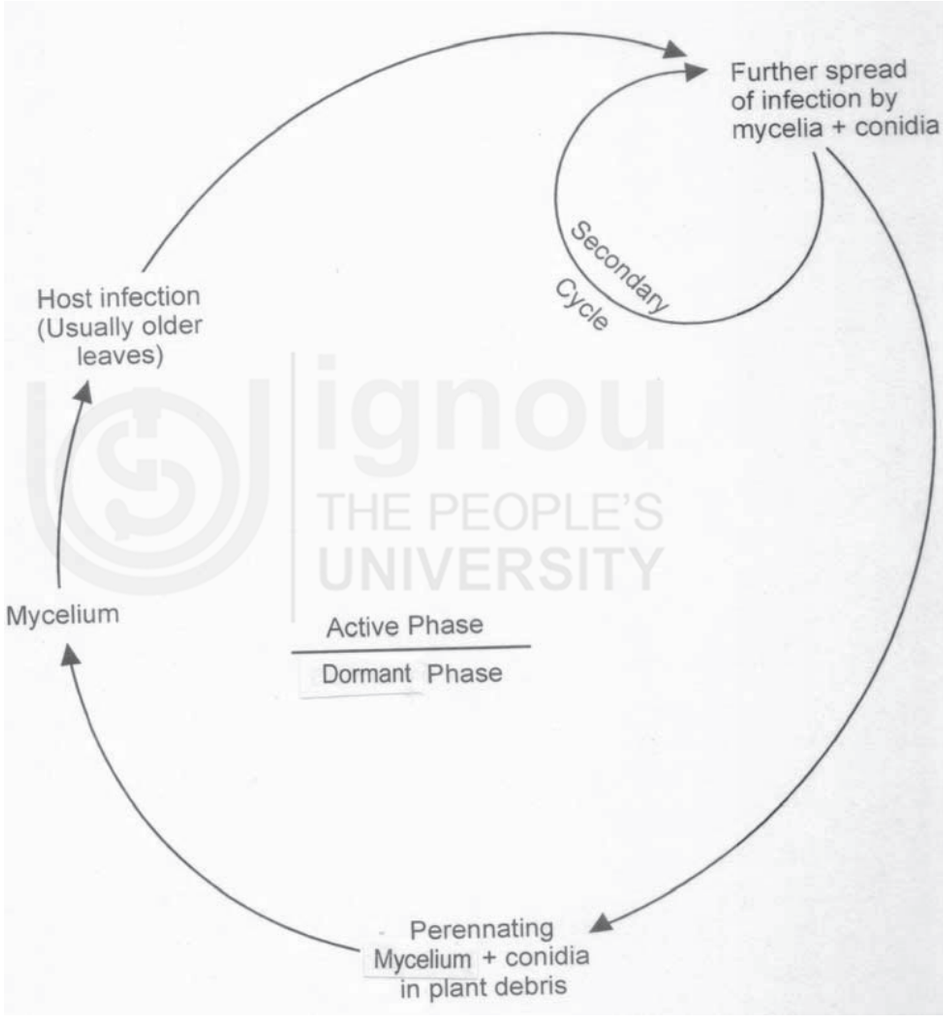


Fig. 10.12: Disease cycle of early blight of potato.

Control: The disease can be controlled by following means:

1) Infected debris of previous year should be burnt to cut down the source of infection.
2) Disinfection of seeds is essential prior to 'sowing'.
3) Spray of 'bordeaux-mixture' on the leaves.
4) Use of fungicides, such as carbamites and calcium arsenates.
5) Employing crop-rotation.

10.4.4 *Puccinia*

Puccinia belongs to the Division Basidiomycota. *Puccinia* is a large genus with more than 700 species. About 150 species reported from India. It occurs as an obligate parasite on cereals, millets and many other crops of economic importance. The most common species is *Puccinia graminis* which mostly attacks wheat and rarely also barley, oat, and rye.

Puccinia graminis is a rust fungus which uses wheat as the primary and barberry as the secondary host. Such pathogens, which require two distinct hosts to complete their life cycle are termed as **heteroecious**.

There are in all five stages in the life cycle of *Puccinia*. Three stages, uredospores, teliospores and basidiospores occur on wheat plant while, the remaining two pycniospores and aeciospores occur on barberry leaves. On wheat the mycelium is dikaryotic and on barberry it is monokaryotic. The mycelium is septate and intercellular with spherical haustoria.

Life cycle on wheat plant

The life cycle of *Pucinia graminis* is shown in Fig. 10.13. The following stages are found on the primary host, i.e., the wheat plant.

Uredium and Uredospores

In the stem, leaf or leaf sheaths of wheat the dikaryotic mycelia grow subepidermally and develop into **uredinial cells**. The uredinial cells form a palisade like layer of hyphal tips below the epidermis and produce urediniospores also called **uredospores**. The urediniospores of *Puccinia* represent conidia, which repeat the dikaryotic phase for several successive generations as long the conditions remain favourable.

A mature uredospore is a stalked structure, bearing a swollen, round, globose or oval body. Each uredospore contains two nuclei and is surrounded by a thick, spiny wall. The wall contains thin areas called germpores. A single uredium (plur. uredinia) may contain 50,000 to 4,00,000 uredospores. The uredinia appear as elongate, reddish-brown or blackish granular pustules and provide a rusty appearance to the host and hence the name of the fungus (rust fungus). The uredospores are carried away by wind from the pustules and when they fall on fresh wheat host, they germinate to form fresh dikaryotic mycelium, thus, uredospores help in asexual multiplication of the fungus during favourable conditions.

Telium and Teliospores

In the late growing season, the mycelium begins to produce teliospores along with uredospores. When teliospores alone are produced in sori or pustules are called teliosori or teleutosori (singl. Teliosorus or teleutosorus). They are dark brown or black. The teliospores are stalked, bicelled, spindle-shaped structures, each constricted slightly at the septum. The wall of the teliospores is thick and smooth and their tip is usually pointed or round. Each cell of the teliospore contains a germ pore. The germ pore is at the apex in the upper cell and it is near the septum in the lower cell.

Each cell of the teliospores is binucleate. Because of the thick wall the teliospores may withstand unfavourable conditions. At maturity, the two nuclei of each cell of the teliospore fuse to form a diploid nucleus.

The teliospore cannot infect the wheat plant. The teliospores undergo a period of rest until the next spring. These teliospores may remain on the dead host plants or in the soil during the resting period.

Each teliospore germinates and produces the basidiospore.

Basidium and Basidiospore

This stage represents the basidial stage. Both cells of the teliospore function as hypobasidia. From each hypobasidium a long tube called promycelium or epibasidium develops. The diploid nucleus of each cell moves into the respective epibasidium and divides meiotically to form four haploid nuclei. Cross walls are formed in between the haploid nuclei, thus forming four haploid cells in each epibasidium. From each of these cells a lateral short, peg-like projection develops which is called sterigma. At the tip of each sterigma a basidiospore is formed. Segregation of strains takes place during basidiospores formation. Thus, two basidiospores in each epibasidia belong to plus strain while the other two belong to minus strain. Each basidiospore is small, unicellular uninucleate and haploid.

The basidiospores are discharged into air with force. They cannot infect the wheat plant. They germinate only when they fall on a barberry (*Berberis vulgaris*) plant which is alternate or secondary host.

Life Cycle on Barberry Leaf

The haploid phase of the life cycle of *P. graminis* is confined to the secondary host, the barberry plant. It consists of primary or haplomycelium and two types of sori, spermagonia and aecia.

The hapoid basidiospores settle on the leaf of a barberry plant and germinate to produce monokaryotic mycelium. The hyphae grow in the intercellular spaces of the host tissue. Within 3-4 days after infection, dense hyphae mats develop all over the tissue and become visible externally on the leaves in the form of small, yellowish, circular pustules. Each pustule represents a spermagonium pustule.

A mature spermagonium is a flask-shaped body, opening externally by a pore called **ostiole**. The cavity of the spermagonium is lined with a palisade-like layer of numerous, short uninucleate, tapering cells, which represent the **spermatiophores.** From the tip of each spermatiophore many, small, uninucleate spores are produced. Near the ostiole some long, pointed hyphae are produced which project out through the ostiole. These are called periphyses. Some of the projected hyphae become very long. They are called receptive hyphae or flexuous hyphae. The spermatia function as male cells and the long receptive hyphae behave as trichogyne.

The transfer of spermatia to the trichogyne is called spermatization. The mature spermagonium secretes a nectar-like liquid which collects at the ostiole region. Insects which are attracted towards the nectar-like liquid

transfer the spermatia from one spermagonium to the trichogyne of another spermagonium. When the spermatia and trichogyne belong to opposite strains, the interventing walls of the spermatium and trichogyne dissolve and the contents of the spermatium pass into the trichogyne. The spermatial nucleus reaches the basal cell of the receptive hypha and thus it becomes a dikaryon.

The well-developed primary mycelium within the barberry leaf produces a globose hyphal mass called protoaecium just below the lower epidermis. This protoaecium develops into an aecium with the development of dikaryotic cells. The basal cells of each aecium become elongated into sporophores or stalk cells. From each of these basal cells a chain of dikaryotic cells are cut off towards the lower epidermis. When these cells divide a large cell and a smaller intercalary cell or disjunctor cell are formed. The larger cells become the aeciospores. The disjuncture cells help in the dispersal of aeciospores. The entire structure is like a cup and is called aecial cup. There is a protective layer or peridium for the aecial cup. Each aeciospore is a polyhedral, binucleate structure with two wall layers. The outer wall layer is thick and smooth, and the inner wall layer is thin and smooth. They are shed in the late spring. They cannot infect the barberry plants. When they fall on the primary host, i.e., wheat, they germinate and develop into dikaryotic mycelia. Thus the life cycle is completed and a fresh cycle starts again. *Puccinia graminis* exhibits a complex life cycle with two hosts, two types of mycelia, five types of spores. Hence *Puccinia* is called a macrocyclic and heteroecious fungus.

Wheat Rusts

Rust of wheat is prevalent worldwide and affects wheat wherever it is grown. The rust fungus attacks all parts of wheat plant above the ground and causes loss by reducing foliage and root development. Consequently, the yield and quality of grain is affected.

The rust fungi are obligate parasites. Most rust fungi produce five distinct fruiting structures with five different spore forms that appear in a definite sequence. Some of the spore stages parasitize a different alternate host plant.

The life cycle of *Puccinia graminis*, a macrocyclic, heteroecious rust fungus is illustrated in the Fig. 10.13.

Wheat crop suffers from three types of rusts:

a) Stem or black rust caused by *Puccinia graminis*,

b) Stripe or yellow rust caused by *Puccinia glumarum*,

c) Leaf or brown rust caused by *Puccinia triticina*.

Control Measures

- Use of wheat varieties resistant to infection by the pathogen. This is the most effective and the only practical means of control of wheat stem rust.
- Eradication of barberry plants in hills, the alternate host of rust fungus and other plants acting as collateral hosts like some grasses. This step eliminates the early season infections on wheat in the areas where uredospores cannot survive winter.

- Clearing of the field between the harvest of one season and sowing of the next, so the primary source of infection, uredospores will be destroyed.
- Application of fungicides such as sulphur, dichlone, and zineb.
- Mixed cropping of wheat and barley also helps in controlling the disease.

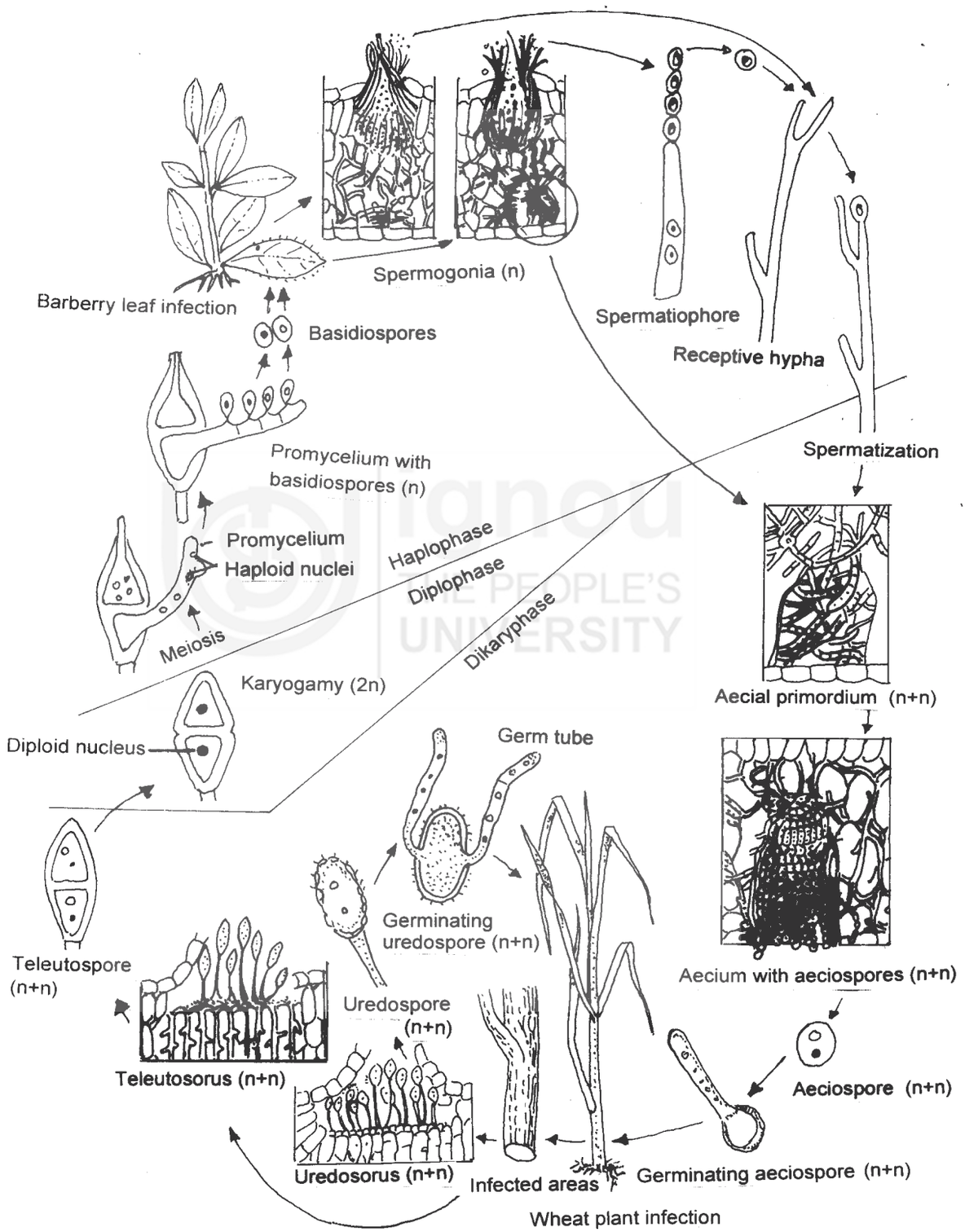


Fig. 10.13: Life cycle of *Puccinia graminis*.

10.4.5 *Agaricus*

Agaricus (Fig. 10.14), often synonymous with the term 'mushroom' has more than 200 species. It belongs to the Division Basidiomycota. It is common in temperate region, growing in pastures and woodland litter. All the mushrooms are saprobes and they spread across the substratum with the help of perennial mycelia. To the naked eye, they are visible as white to brown, moderate to large fruiting bodies, the basidiocarps. Some of the common species are *A. campestris* (field-mushroom); *A. arvensis* (horse-mushroom); *A. xanthodermus* (yellow-stainer) and *A. tabularis* (ring-mushroom).

Life Cycle of *Agaricus*

Somatic Structure

Agaricus thallus is represented by three kinds of mycelia the primary, the secondary and the tertiary. The primary mycelia represent the somatic phase of the life cycle. It grows and protiferates on the substratum and could be perennial. It is capable of indefinite growth. Each primary mycelium develops from a haploid basidiospore. This mycelium is filamentous, branched and conspicuously septed. Each of the hyphal cell of the mycelium is uninucleate. The septum development is centripetal (from periphery to center) and incomplete. It results in formation of a central pore. Such pores possess barrel-shaped swellings covered with dome-shaped membranous spore caps. Such a structure in the transverse wall of the mycelium is called **dolipore septum**. It is suggested that these septae function as sieve, possibly permitting the passage of some cellular components across the hyphal cells, except the nuclei.

Secondary Mycelium

Like majority of other members of the Division Basidiomycota, *Agaricus* does not produce any sex-organs. The formation of secondary mycelium is preceded by somatic-hybridization between two compatible homokaryotic primary mycelia.

The mycelial branches arising out of a basidiospore are not compatible for somatic-hybridization. Hence, *Agaricus* is heterothallic. During this process, two hyphal cells belonging to mycelia of different (opposite) strains interact with each other. The cell walls at the point of contact, get dissolved and a binucleate cell is formed following plasmogamy of two uninucleate cells. This binucleate cell possesses two nuclei of two different origins (heterokaryotic) and is termed as a **dikaryon.** Whenever this cell divides, the resultant daughter cells also get two heterokaryotic nuclei. Such heterokaryotic feature of the mycelium is maintained by a specialised mode of nuclear division accompanied by morphologically visible structures, the clamp-connections Fig. 10.7. Such clamp connections help maintain **dikaryotization.** The resultant branched, septate, dikaryotic, heterokaryotic mycelium constitutes the secondary mycelium.

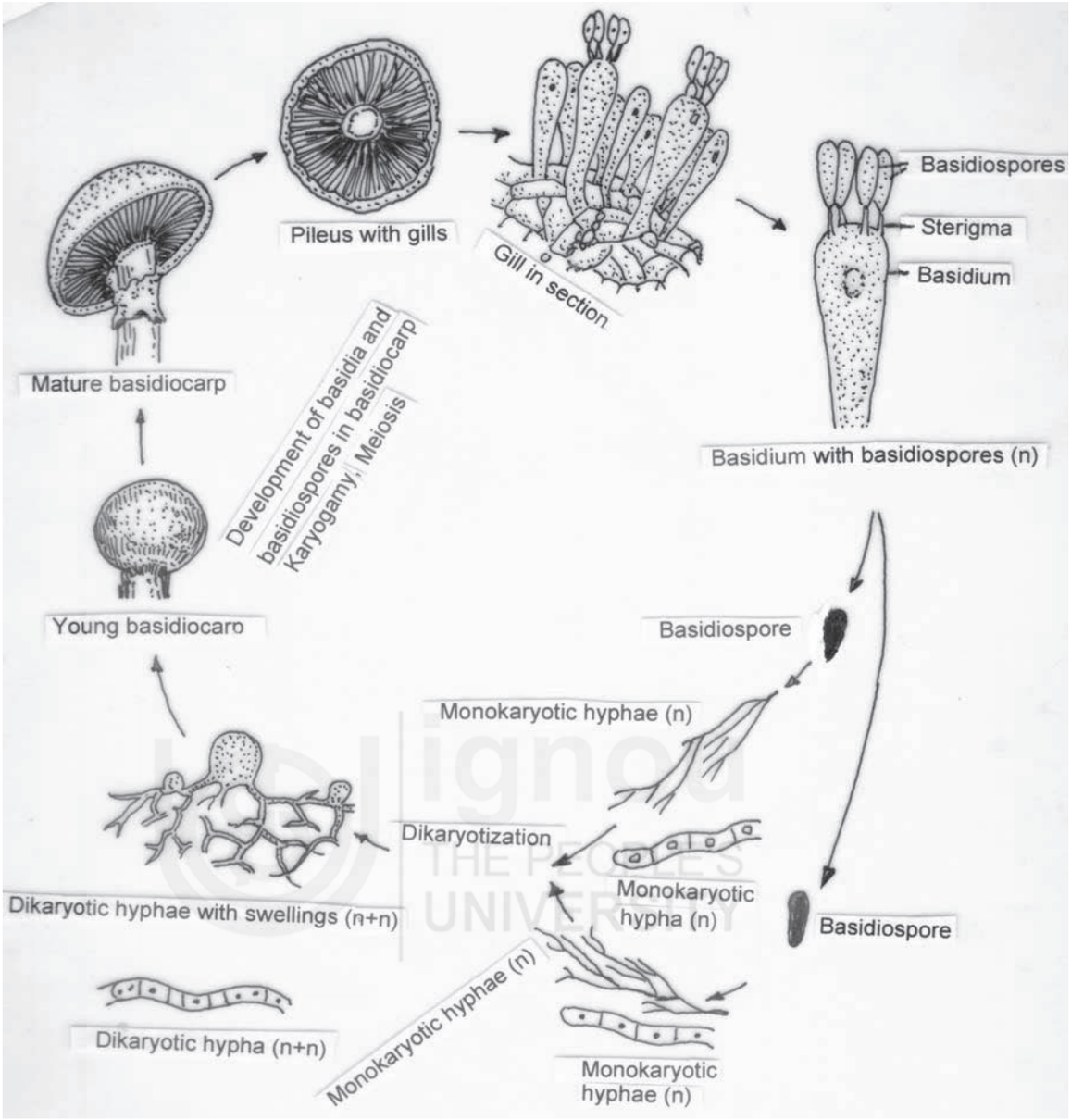


Fig. 10.14: Life cycle of *Agaricus*.

Tertiary Mycelium

The tertiary mycelium of the *Agaricus* is represented by the organised, specialised tissue that leads to the development of the fruiting body, the **basidiocarp.**

Development of a Basidiocarp

The initiation of a basidiocarp starts with the formation of a dikaryotic secondary mycelium. Such mycelium spreads across the medium forming a dense network. At the peripheral ends of the network, small knob-like swellings are formed and they become upright. Such swelling consisting of heterokaryotic mycelia increase in size and become visible to unaided eye as small buttons called button stage of development. Each of them later develops into a basidiocarp.

Structure of a Basidiocarp

Each basidiocarp develops a rhizomorph (refer Unit 9). A mature basidiocarp is white/whitish and consists of a short stalk, the **stipe** with an **annulus** about halfway up (Fig. 10.5). The stipe supports an umbrella (hat-shaped) **pileus**. The pileus is broadly expanded or remains flat. On the underside of the pileus, many radiating gills (lamallae) are formed. These may be pink when young, and purple-black at maturity. The gills are free from the stipe, but are the extension of hyphae of pileus. The mycelium within the gills are very compactly organised. The centre of the gill is termed as **trama**. The peripheral cells or trama are short, compact and constitute **sub-hymenium.** The sub-hymenium layer terminates into a hymenium (hymenial layer). This layer consists of relatively free, club-shaped cells rich in protoplasm and arranged in a palisade manner. A few of these cells remain slender and sterile and are called **paraphyses** (singl. paraphysis). The rest, stout, cells become the **basidium** (pl. basidia). You should remember that all the cells within this basidiocarp are dikaryons and the nuclei are of heterothallic origin. The nuclei within the basidium, now fuse, to produce a diploid nucleus by an event called **diploidisation**. Thus, the mature basidium represents a **diploid** phase in the life cycle of *Agaricus*. This is a short-lived phase. The diploid nucleus undergoes meiosis. The basidum now has 4-haploid nuclei. At the terminal end, on the margins of a basidium four cells are formed. These are termed basidiospores. These basidiospores are attached to the basidium with a small stalk, the sterigmata. Each of the four basidia now get a haploid nucleus out of the four nuclei produced at meiosis in the basidium, two are of (+) strain and the two are of (–) type.

Upon release and on a suitable substratum a basidium produces a germ-tube, which grows into a haploid, septate and branched monokaryotic, primary mycelium.

SAQ 5

Fill in the blanks with appropriate word(s)

a) Meiospores in *Rhizopus* are produced in ..... .

b) ..... is the sexual phase of *Penicillium.*

c) Early blight of potato is caused by ..... .

d) ..... exhibits heteroecious life cycle.

e) ..... help maintain dikaryotization in secondary mycelia of *Agaricus*.

f) Nuclei can pass from one hyphal cell to the neighbouring hyphal cell of a mycelium in the fungi belonging to division ..... .

g) Zoospores in chytrids possess ..... flagellum.

10.5 SUMMARY

In this unit you have learnt that:

- True-fungi representing kingdom Fungi consists of four divisons: Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota. The organisms placed in these divisions exhibit distinct modes of reproduction. The asexual phase is called anamorph, while pleomorph represents the sexual phase also called perfect phase. Those Ascomycota or Basidiomycota members wherein only imperfect, anamorphic phase is known are placed in a class Deuteromycetes (Fungi Imperfecti).
- In True-fungi the mycelium if septate the septum is incomplete. Septum formation is centripetal. The septal pore possesses Woronin bodies in Ascomycota while dolipore-septum is characteristic of mycelial septa in Basidiomycota. All protoplasmic contents including nucleus can pass through septum in Ascomycota. However, except nucleus all protoplasmic contents can pass through dolipore septum in Basidiomycota. The mycelia in Zygomycota are aseptate, and coenocytic.
- The cell walls in true-fungi are made up of chitin and glucan. The reserve food material is glycogen. Except for some stages in the life of chytrids, the motility is absent.
- Asexual reproduction is through fragementation, budding, sporangiospores, conidia, sexual structures could be zygospores, ascospores or basidiospores. Complex sexual fruiting bodies are characteristic of Ascomycota and Basidiomycota.
- The terminal position of hyphae in true-fungi are characterised by the presence of vesicles. Mycelia tips of Zygomycota and Chytridiomycota possess only macrovesicles, small microvesides in addition to larger macrovesides are present in the distal region of hyphae in Ascomycota and Basidiomycota. This combined vesicle unit is termed Spitzenkörper.
- Chytrids are very small organisms detected only by microscopic examinations. These may be epibiotic or endobiotic.
- Dikaryotization is distinct phase in the sexual life of Ascomycota and Basidiomycota.
- *Rhizopus* exhibits planogametic fusion during sexual phase.
- Antheridium, ascogyne, ascogonial filaments, crozier formation, ascus, ascospore and cleistothecium are important reproductive structures in the life of *Talaromyces*, the pleomorphic genus of *Penicillium*. It reproduces asexually through phialidic state.
- In *Agaricus* life cycle – there is primary, secondary and tertiary mycelia formation; dikaryotization in secondary mycelia is through clamp-connections; rhizomorph development, basidiocarp formation; karyogamy in basidium and subsequent meiosis and external haploid basidiospore are the key stages.

- The heteroecious, heterocyclic life cycle involving two hosts is characteristic of rust fungus, *Puccinia graminis*. Sexuality in *Puccina* is reduced to fusion of two nuclei - spermeation.
- Multicelled, conidia are the asexual units of *Alternaria*, representing its anamorphic state.
- Ecologically, the true-fungi are valuable saprotrophs, serving as natural decomposers. These fungi may be valuable as source of food, medicines, drugs, hallucinogens, and enzymes. They may be severe food spoilers in field as well as in storage. They cause various diseases of plants, animals and human beings.
- Some true-fungi also occur as symbionts mostly in lichens and as mycorrhiza.

10.6 TERMINAL QUESTIONS

1. Describe the sexual phase of life cycle of *Puccinia graminis*.
2. List the divisions of True-fungi and mention their characteristics.
3. Write a note on the industrial applications of true-fungi.
4. Compare the structures of mycelia of *Rhizopus*; *Penicillium*, and *Agaricus*.
5. Comment on the rule of Crozier in Ascomycota.

10.7 ANSWERS

Self-Assessment Questions

1. a) Zygomycota; b) chytrids; c) Basidiomycota; d) dikaryotic.
2. a) Ascomycota; b) aplanospores; c) Chytridiomycota; d) glucan; e) glycogen.
3. a) – (iii); b) – (iv); c) – (ii); d) – (i).
4. a) amylase; b) *Ustilago*; c) *Clavatia*; d) parasitic.
5. a) zygosporangium; b) *Talaromyces*; c) *Alternaria solani*; d) *Puccinia graminis*; e) Clamp-connection; f) Ascomycota, (g) whiplash.

Terminal Questions

1. Refer Subsections 10.4.4 and Fig. 10.14
2. Refer Subsections 10.2.1 to 10.2.4
3. Refer Tables 10.2 & 10.3
4. Refer Subsections 10.2.2, 10.2.3, and 10.2.4
5. Refer Subsection 10.2.5 and Fig.10.6

10.8 GLOSSARY

Aeciospore : A binucleate spore of a rust fungus produced in an aecium.

Aecium (pl. aecia) : A structure produced on an infected host tissue by a certain rust fungi.

Appendage : Sterile, mycelial, free outgrowth of a fruiting body of Ascomycota.

Apothecium (pl. apothecia) : Open, saucer-shaped fruiting body in Ascomycota.

Ascocarp : A spore-producing body containing asci.

Ascogenous hypha : A specialised hypha that gives rise to one or more asci.

Ascogonium : The female gametangium in Ascomycota.

Ascospore : A meiospore borne in an ascus.

Ascus : A sac-like cell generally containing a definite number of ascopores, characteristics of Ascomycota.

Basidiocarp : A spore-producing body that bears basidia.

Basidiospore : A meiospore borne on the outside of a basidium following karyogamy and meiosis characteristic of Basidiomycota.

Basidium : A structure bearing on its surface a definite number of basidiospores.

Chitosome : A small cytoplasmic vesicle containing chitin synthetase.

Chytrid : A general term used to describe a member of Chytridiomycota.

Cleistothecium (pl. Cleistothecia) : A completely closed ascocarp.

Columella (pl. columellae) : A sterile structure within a sproangium, often extension of stalk.

Conidiophores : A simple or branched hypha arising from somatic hypha and bearing on its tip or side one or more conidia.

Conidium (pl. conidia) : A non-motile asexual spore.

Deuteromycetes : Fungi that only reproduce asexually.

Dikaryon : A pair of closely associated, sexually compatible nuclei.

Dikaryotic : Pertaining to a cell that contains a dikaryon.

Dolipore Septum : A septum with a central pore surrounded by a

barrel-shaped swelling of septal wall and covered on both sides by a perforated membrane.

Heterothallic : Self sterile individuals requiring the union of two compatible thalli for sexual reproduction.

Homothallic : Fungi in which sexual reproduction takes place in a single thallus.

Hymenium : A fertile layer consisting of asci or basidia.

Monokaryotic : Condition of having a single nucleus in each hyphal cell.

Monophyletic : Of a single line of descent.

Muriform : A spore with both transverse and longitudinal septa.

Mushroom : A fleshy, sometimes tough, umbrella-shaped basidiocarp.

Paraphyses : (sing. paraphysis) sterile, basically attached structures in the hymenium of perithecia, apothecia.

Parasexuality : A process in which plasmogamy, karyogamy and haploidization take place in sequence, but not at specific points in the life cycle of an individual.

Peridium : The outside covering or wall of a fruitification.

Periphyses : (sing. periphysis): short, hair-like growths in the form of a fringe living inside of an ostiole or pore in a stroma.

Perithecium : A closed ascocarp with a pore at the top.

Polyphyletic : Not sharing a common ancestry.

Receptive hypha : The structure with which spermatium fuses.

Spermatium (pl. spermatia) : A non-motile uninucleate, spore-like male structure that transfers its contents into a receptive female structure during plasmogamy.

Spermatization : Plasmogamy by union of spermatium with a receptive structure.

Spitzenkörper : A refractive region near the tip of a hypha in certain fungi, the cytosplasm in this region is granular and contains a number of small vesicles.

Sterigma (pl. sterigmata) : A small hypha branch or structure, which supports a sporangium, a conidium or a basidiospore.

Trichogyne : The receptive hypha of the ascogonium that fuses with the male cell, often long and hair-like.

Woronin-body : An electron-dense, spherical body found in the hypha of Ascomycota and Deuteromycetes generally near the septa.

Zygophore : A special hypha capable of developing into a progametangium in zygomycota.

Zygospore : A resting spore formed after the fusion of two gamentangia.

10.9 FURTHER READING

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UNIT 11

FUNGI: LICHENS AND MYCORRHIZA

Structure

11.1 Introduction
Objectives

11.2 Lichens
General Account
Reproduction
Significance of Lichens

11.3 Mycorrhiza
Ectomycorrhiza
Endomycorrhiza
Ecological Significance

11.4 Summary

11.5 Terminal Questions

11.6 Answers

11.7 Glossary

11.8 Further Reading

11.1 INTRODUCTION

In this last unit of the block you would study the fungal symbiotic and mutualistic associations in lichens and mycorrhiza (pl. mycorrhizae). While in lichens the fungi cohabit algae, in mycorrhiza fungal relationship is principally confined to plant roots. Association with algae in lichens has helped them to pioneer the terrestrial habitat millions of years ago. Mycorrhizal association on the other hand has helped land vascular plants to colonise terrestrial habitats, help natural terrestrial ecosystems via seedlings establishment. Mycorrhizae are known to improve nutritional deficiencies of sand-dunes, recently disturbed soils, soil heaps, and areas covered with volcanic ash. Mycorrhiza is also helpful in linking plants together into communities that are more resilient to stresses and disturbances. You will also study the ecological and economic significance of lichens in this chapter.

Objectives

After studying this unit, you will be able to:

- describe the structure, distribution and anatomy of lichens;
- discuss various types of reproduction in lichens;
- discuss fungal-algal partnership in lichens;
- describe ecological and economical importance of lichens;
- describe the mycorrhizal symbiotic associations with plant roots;
- define and differentiate between ecto- and endo-mycorrhiza; and
- discuss the significance of mycorrhizae in terrestrial ecosystems.

11.2 LICHENS

The lichens (pronounced as “lai-ken”) are the organisms which are somewhat unusual in structure. They are composed of completely two different symbiont organisms – green algae or cyanobacteria (blue-green algae) and colourless fungi. The unique feature of fungi in lichens is the ability to form lichen thallus which they are incapable of individually. More than 13,500 species of fungi are reported in lichens. This group of organisms has a distinct morphology and a special character. They are found in all habitats including inhospitable tropical deserts, rock faces, tree bark, roofing tiles, polar regions and even on the surface of granite boulders. In such regions they represent pioneer and dominant vegetation and are among the oldest living beings on Earth. They are also regarded pioneer of terrestrial habitat.

When lichen has three components: fungus, green alga and cyanobacteria, the association is tripartite.

In the following text you will study the range of structure, anatomy and reproduction in lichens. We will also discuss the symbiotic relationship between fungal-algal partners. Lichens are ecologically very useful. They are also used for human consumption and for the production of chemicals.

11.2.1 General Account

Lichens as Individual Organisms

Lichens represent symbiotic association of a fungal partner with an alga. Although the fungal component – **mycobiont** and the algal component – **phycobiont** can be grown separately lichen thallus develops only when they are together. Fungal component represents exhabitant and the algal component represents inhabitant. As an organism lichen shows unique morphological and biochemical characters. The two symbionts remain cytologically distinct despite ‘lichenization’.

The mycobiont unlike the phycobiont is unique for each species of lichen. Nearly 98 per cent of lichen fungi are members of Ascomycota, the rest may have a Basidiomycota or Deuteromycota member. The morphology of a lichen is believed to be determined by the fungal partner. Accordingly, we have ascolichens, basidiolichens and deuterolichens.

The phycobiont is the photosynthetic partner, which is either blue-green alga or green alga. About 85 per cent of algae components are green algae and ten percent blue-green algae. Five per cent of lichens are tripartite.

There are nearly 37 algal genera found in lichens. The commonest partners are green algae *Trebouxia* (Chlorococcales) and – *Trentepohlia* (Chaetophorales) and the cyanobacterium – *Nostoc*. Sometimes more than two or even three algae may be found in the same lichen. Algae fix carbon dioxide by photosynthesis. The blue green algae in addition fix nitrogen and thus provide nutrition to the mycobiont. Laboratory studies show that the algal component can be grown in cultures without the fungus and it does not seem to depend on the fungal partner except for physical protection. The algal and fungal components of lichens can be separated and cultured in test tubes.

Most attempts to recombine them were unsuccessful initially. However, it has been possible to reconstruct about 30 species of lichens successfully in the laboratory (Fig. 11.1).

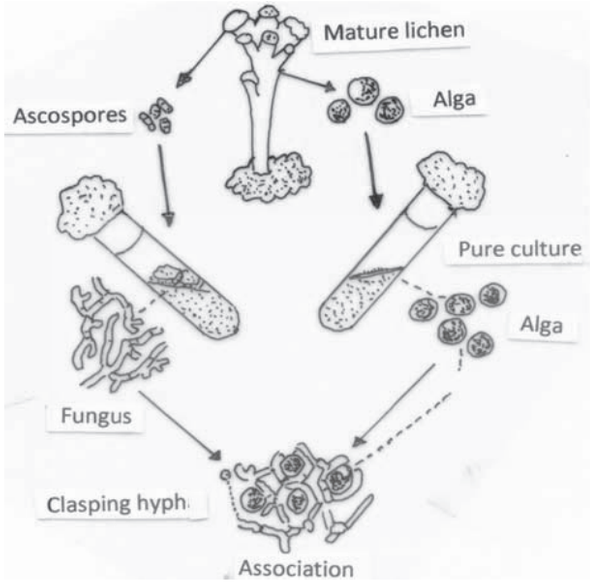


Fig. 11.1 : Diagrammatic presentation showing separation and culture of lichen components and the reconstruction of lichen from them.

Structure and Anatomy of Lichens

Structure

The plant body in lichen is a thallus that lacks differentiation into stem, roots or leaves. The thalli are generally round in outline between 1 cm to 30 cm in diameter. They may either be scattered or clustered together occupying a large area of substratum. Distinct growth forms and colours are the characters based on which we can identify the type of lichen.

There are three major morphological forms of lichens.

i) **Crustose** forms like *Graphis*, *Lecidea* and *Haematomma*. Thallus is a crust-like (Fig. 11.2 a) coloured patch growing on bare rocks and tree trunks.

ii) **Foliose** forms like *Parmelia*, *Peltigera*, *Collema*, *Parmotrema* and *Gyrophora.* Thallus is leaf-like, flat and dorsiventral with lobed or irregular margins (Fig. 11.2 b). It is loosely attached to the substratum. In cross section it appears differentiated into layers.

iii) **Fruticose** forms like *Usnea*, *Cladonia* and *Ramalina*. Thallus is branched, bush-like, shrubby and (Fig. 11.2 c) sometimes several meters long hanging from tree branches. It is internally differentiated into layers.

Some other forms of lichens are: filamentous (hair-like); leprose (powdery); squamulose (small scales), and gelatinous.

The majority of lichens are of the crustose type.

Besides variable morphology lichens also show striking colours such as grey, yellow, orange, yellowish or bluish green, black or white because of the presence of pigments.

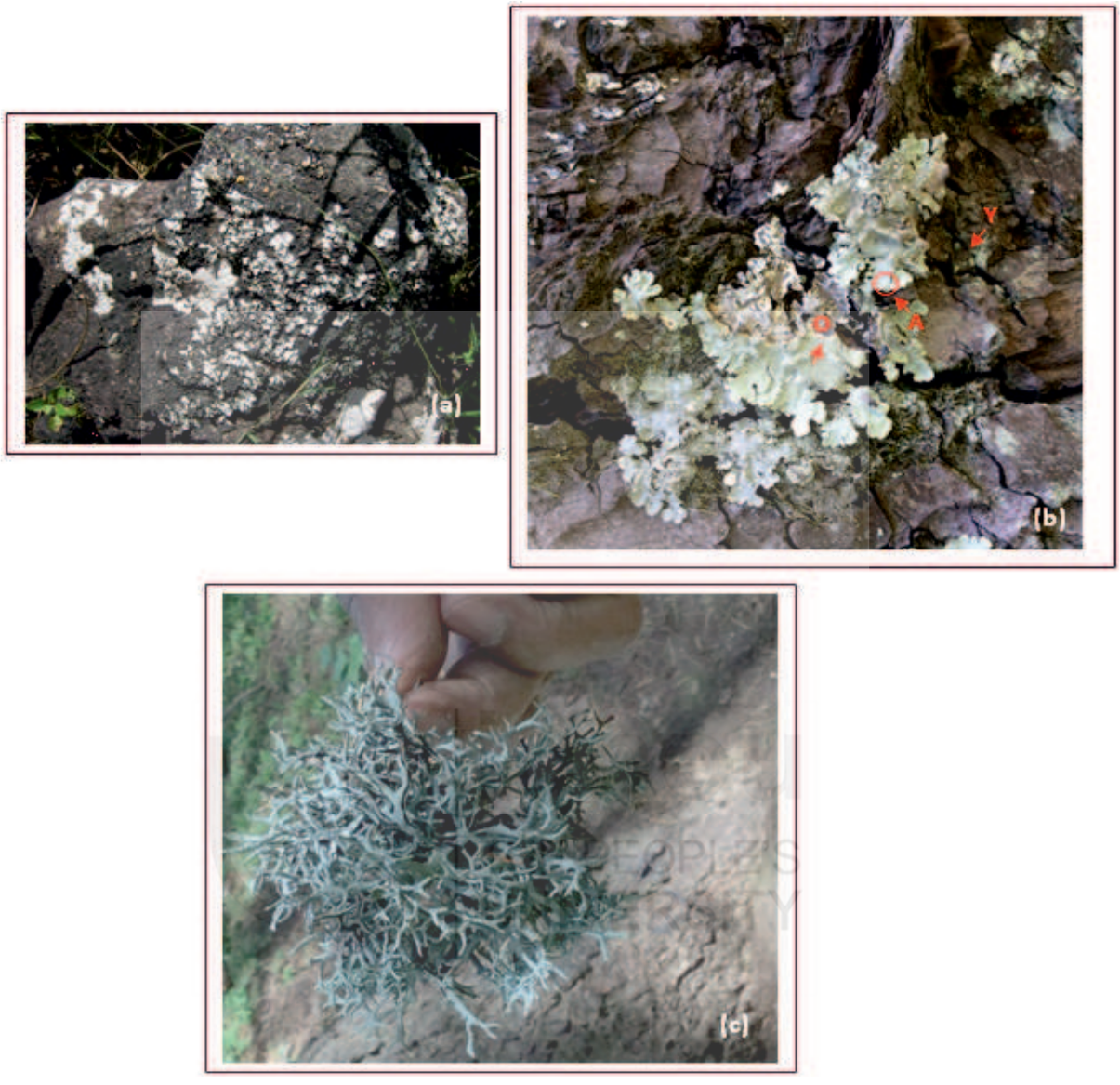


Fig. 11.2 : a,b) Surface views of crustose and foliose lichens growing on rock and branch of tree respectively; In b) note apothecium (A), old (O) and young (Y) portions of the thallus; c) Fruticose lichen. (Courtsey: A.K Kavathekar, 2017).

The ability to form thallus is a unique feature of lichen fungi. A vertical section of foliose lichen when examined under a microscope shows four zones: uppermost with densely interwoven fungal hyphae. A few micron thick this zone is called **upper cortex**. The cortex is principally a protective zone. Below cortex lies an **algal zone**. This zone possesses embedded fungal hyphae wherein each photobiont is encircled by mycobiont. This is a photosynthetic zone. Below this zone lies medulla, where interwoven loosely arranged fungal hyphae are present without any algal association. The lowermost zone is similar to the upper most zone and is called **lower cortex.** Some hyphal branches emerge from lower surface to form rhizinae or rhizines. The rhizinae help in attachment of lichen thallus to the substratum (Fig. 11.3 b).

In some lichens tissue regions are poorly defined, so that the mycobiont and photobiont tissues are spread uniformly thoughout the thallus. This condition is

known as *homoimerous*, e.g., most of the lichens where phycobiont component is cynaobacteria. The more stratified lichens are termed *heteromerous.*

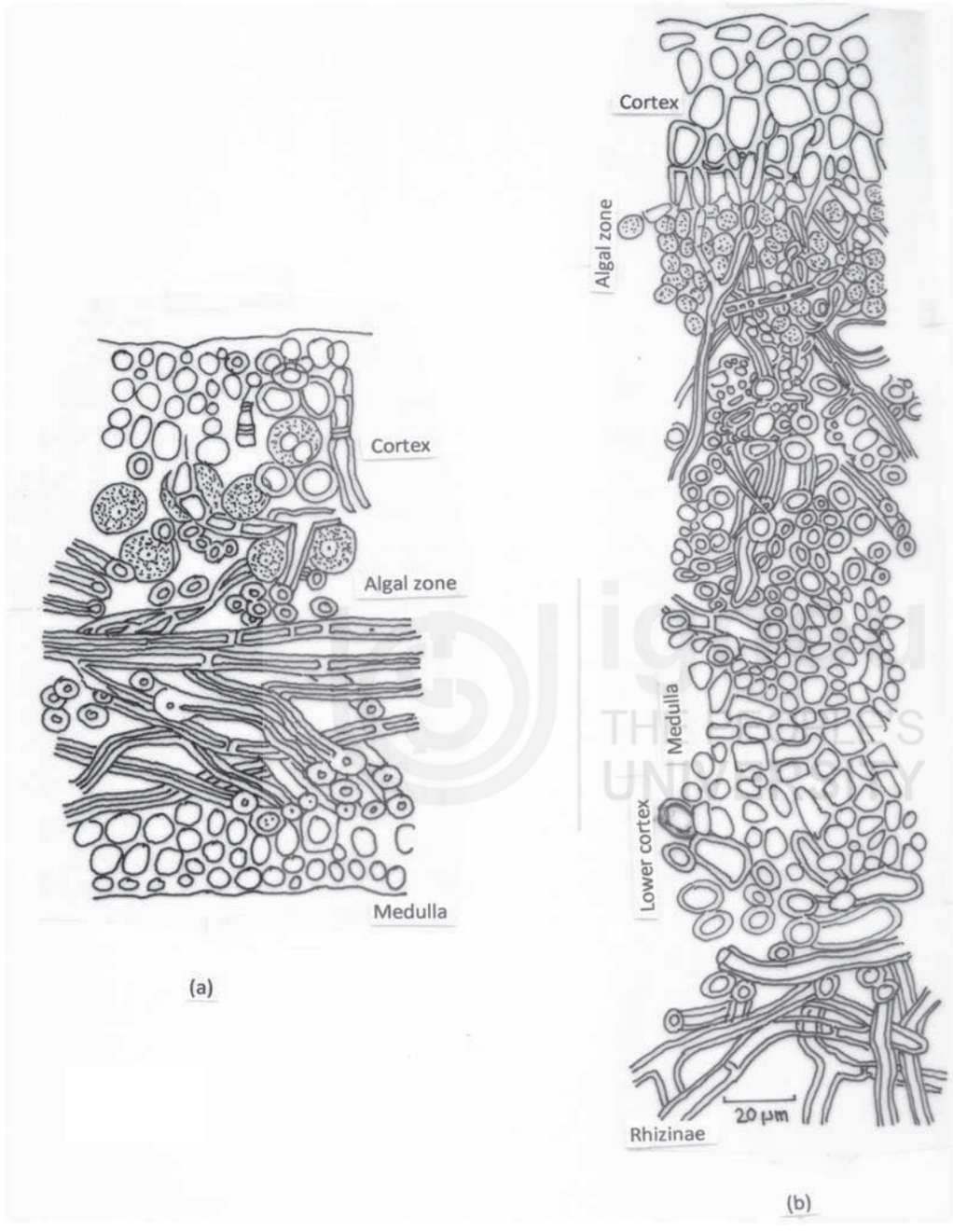


Fig. 11.3 : Lichen thalli in vertical section: a) Crustose; and b) Foliose lichens. Redrawn from Webster & Weber, 2007.

11.2.2 Reproduction

Vegetative Reproduction

New patches of lichens grow when small pieces of lichen are broken from the main thallus. In addition, a variety of vegetative structures **soredia, cephalodia** and **isidia** arise from the main thallus containing partners, the phycobiont and the mycobiont.

1) *Soredia* : Each soredium is non-corticated, non-pigmented and whitish, mainly arising from medulla. Each soredium consists of a few medullary hyphae enmeshed around algal cells (Fig. 11.4 a).

2) *Cephalodia* : These are dark-coloured, gall-like outgrowths of the thallus. In cephalodia, the cyanobacterium photobiont may be incorporated along with a green photobiont in specialised, mycobiont chambers. Thus, a cephalodium may be a reproductive unit comprising species from three kingdoms: Monera, Protista and Fungi (Fig. 11.4 b).

3) *Isidia* : These are cylindrical, finger-like outgrowths on the thallus when fragmented, produce new thalli. These could be granular, spherical, ellipsoidal, fusiform, and cylindrical in shape (Fig. 11.4 c).

Asexual Reproduction

Various types of asexual spores, **oidia**, **pycniospores** and **conidia** are produced like in any fungus and this is the most common method of reproduction.

Sexual Reproduction

Information on this aspect is very limited and is known only in the case of some ascolichens like *Collema*. It is very similar to the sexual process of an ascomycota fungus.

The male sex organs are known as **spermagonia** which produce small non-motile male cells called **spermatia**.

Reproductive structures in lichens are shown in Fig. 11.5. The female sex organs are called **ascogonia** which develop from the medulla of the lichen thallus. The ascogonium has terminal long multicellular hair like projection called **trichogyne** and a basal portion which acts as **oogonium**. Fertilization occurs by the transfer of spermatium to the tip of trichogyne after which it passes down to the basal portion. A number of ascogenous hyphae are produced which form the ascocarp. The ascocarp is a dish-shaped – **apothecium**. Each **ascus** produces eight **ascospores**. Ascospores germinate and when the hyphae come in contact with suitable algal cells they develop into new lichen thalli.

11.2.3 Significance of Lichens

The nature of fungal-algal association in a lichen is considered as symbiosis where both the partners derive equal benefit from each other. This association is also known as mutualism. Though in some lichens it is observed that the algal cells are penetrated by haustoria (as in parasitic fungi) they are not killed or weakened. There seems to be a balance of give and take between the partners.

It has been shown by experiments that nearly 70 to 80 per cent of the total carbon compounds synthesised by the alga (ribitol, mannitol and arabitol) during photosynthesis are passed on to the fungus.

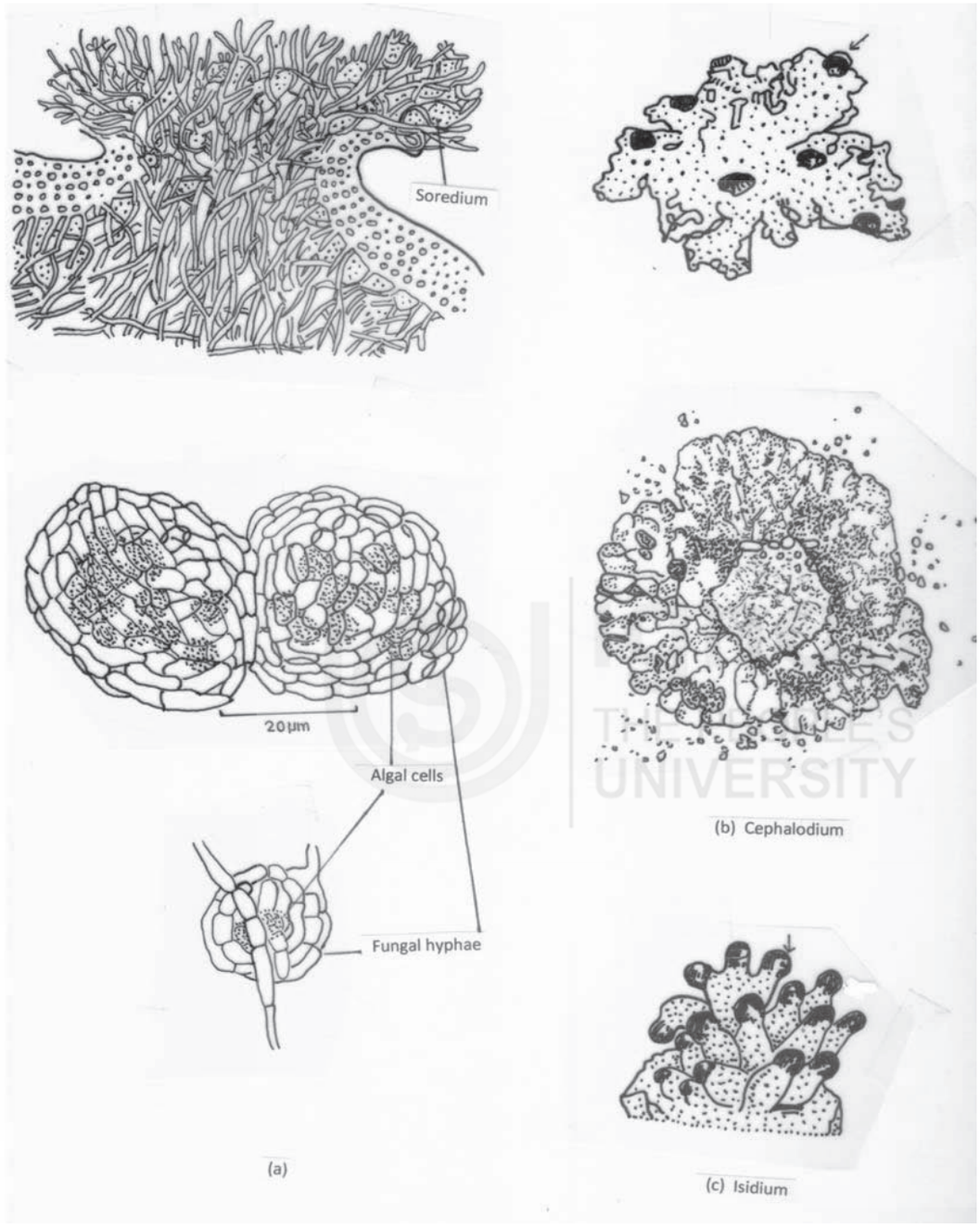


Fig. 11.4: Three types of reproductive structures in lichens: a) Soredia, V.S. thallus (top), algal cells (middle) and, an enlarged view of algal cells and fungal hypha (bottom); b) Cephalodia (surface view top), and a cephalodeum enlarged (middle); c) Isidia (surface view, bottom), enlarged (right). Credit: a) Middle and bottom figures; and b) middle figure redrawn from Webster & Weber, 2007.

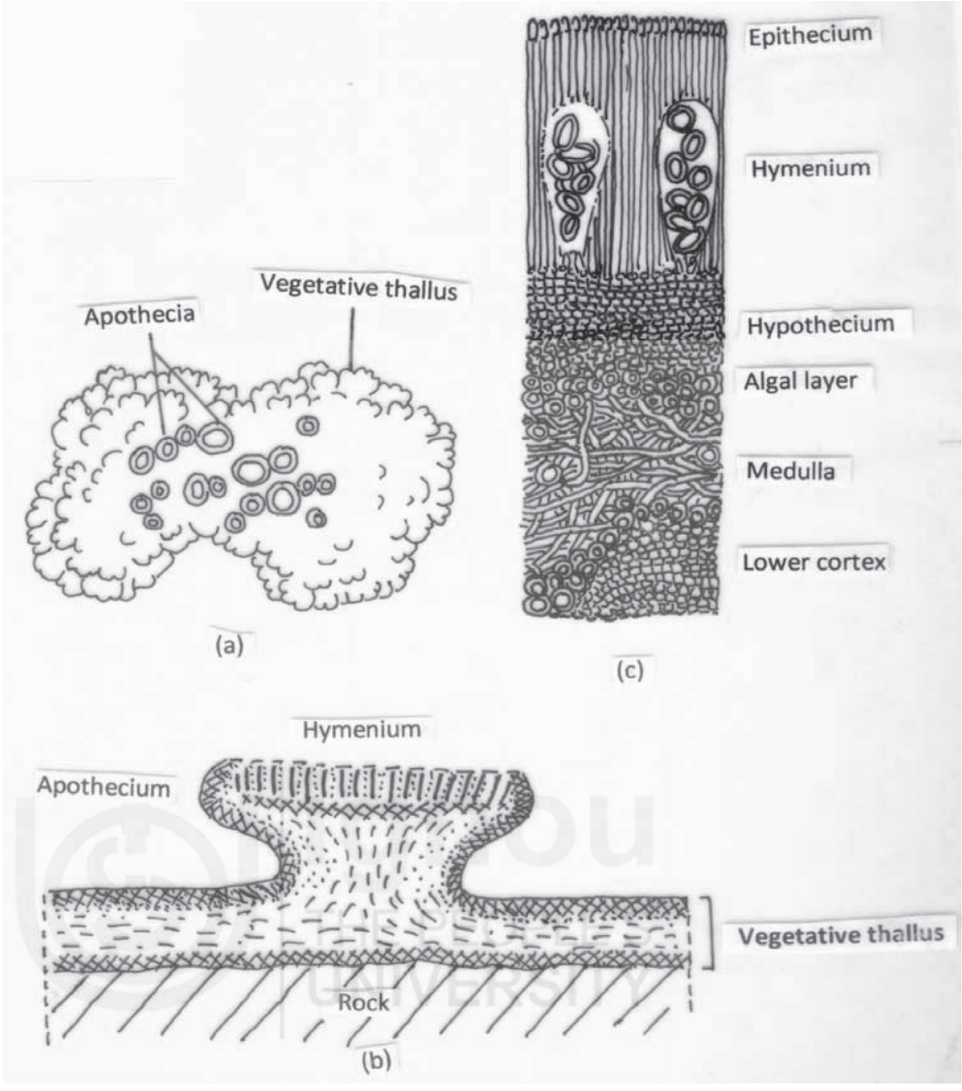


Fig. 11.5: Reproductive structures in lichens: a) Surface view of a lichen thallus showing apothecia; b) Diagrammatic representation of vertical section of a thallus passing through an apothecium; c) A portion of vertical section of thallus passing through an apothecium enlarged.
Credits: (a,b) Ingold & Hudson 1993; and (c) Hale, 1979.

In *Peltigera* where the algal partner is a cyanobacterium (*Nostoc*) which also fixes nitrogen, in addition to carbon compounds, the nitrogen compounds like ammonia are also supplied to the mycobiont. However, it is difficult to say what the alga receives from the fungus in return. Probably the fungal hyphae provide house to the algal cells and protect them from drying, excessive light and other adverse environmental conditions. The loosely interwoven hyphae of the medulla facilitate gas exchange for photosynthesis. However, the opinion about the nature of this association is controversial. Some scientists regard algae as the victims rather than partners imprisoned by the fungal tissue. They consider this association as 'controlled parasitism'. Others believe that it is unique and the finest example of mutualism because of the healthy appearance and long life of algal cells.

Lichens are found growing in many places where other organisms might perish. They are found on bare rocks, in tropical, sub-tropical, temperate and

freezing polar regions. Some are found to survive on rocks where temperature may reach 50°C.

Most lichens are slow-growing, at the rate of about 1 mm per year but are long-lived. In Arctic regions lichen thalli even 4500 years old are found. They have been found on the highest mountains in Himalayas.

On the newly exposed rocks and volcanic regions lichens are the pioneer vegetation as they are the first to inhabit these regions. By their activity they cause the weathering of rocks, build up organic debris, and make the surface suitable for the growth of higher plants. The cyanobacterial lichens contribute nitrogenous compounds also.

Lichens are most abundant in tropical rain forests. Lichens profusely cover tree trunks, branches, and leaves of all plants.

The association between a heterotrophic fungus and a photosynthetic alga is highly successful and productive in the ecological sense, and this is reflected in the distribution of lichens in diverse habitats all over the Earth.

Lichens as Food

In many inhospitable areas like polar regions, rocks and deserts, the only vegetation available to animals is lichen. *Cladonia rangiferina,* known as reindeer moss is widely eaten by arctic animals such as reindeer and caribou. Sheep and land snails browse much on fruticose lichens growing on the soil.

In some places such as Libyan desert the lichen *Lecanora* is collected and eaten by people. In Japan, foliose rock lichen *Umbilcaria* is eaten as salad. In Iceland many local lichens are consumed as food.

Lichens as Indicators of Pollution

Lichens can absorb not only water vapour from the atmosphere but also various pollutants including fluoride, ozone, NO_2, PAN and herbicides. They are particularly sensitive to sulfur dioxide and radioactive elements – strontium and caesium. Nitrogen fixation is most sensitive to SO_2 followed by photosynthesis and respiration. Consequently, the size of the thallus is reduced, fruiting is suppressed and the colour is also affected. Because of this sensitivity, detailed examination of lichens in an area can determine the degree of atmospheric pollution including radioactive fall-out during nuclear tests.

Other Uses of Lichens

The medicinal value of lichens was recognised in folk medicine long ago and is still being used widely. *Lobaria pulmonaria* is useful for lung diseases, also *Peltigera canina* for hydrophobia.

Many lichens contain antimicrobial properties. Usnic acid from *Usnea* is effective against fungi, bacteria and other pathogens of man.

Substances obtained from lichens can also control plant diseases like tomato canker and tobacco mosaic virus.

Before the advent of synthetic dyes lichens were the source of coloured substances used for dying textiles. *Roccella, Parmelia, Ochrolechia, Evernia* are some of the lichens used for the extraction of dyes like orcin which can be used to give shades of red, purple and brown to wool.

Orcein, derived from lichens is used in biological laboratories for staining nucleus in plant and animal cells. Likewise litmus, the acid-base indicator is extracted from the lichen *Roccella*.

Lichens contain various types of essential oils which are used in the manufacture of perfumes.

SAQ 1

a) In the following statements fill in the blank spaces with appropriate words.

i) The fungal partner in lichen is called ..... and the algal ..... .

ii) In 98% of the lichens the fungal partners belongs to ..... .

iii) The algal partner of lichens could be ..... or ..... .

iv) The upper and lower hyphae of fungal partners in lichen thallus are called ..... and the central loose hyphae are called ..... .

v) The two most common algae in lichen symbiosis are ..... and ..... .

vi) The cyanobacteria involved in symbiosis in lichen is ..... .

b) Indicate which of the following statements are true and which are false.

i) The fungal partner of lichen can be grown separately but not the algal partner.

ii) A lichen may have 2 or 3 algal partners.

iii) Fungal and algal partners can be cultured in the laboratory separately and reconstructed into lichen again.

iv) Lichens are not capable of fixing CO_2.

v) When lichen has *Nostoc* as an algal partner it can fix CO_2 as well as nitrogen.

c) Fill in the blank spaces with appropriate words.

i) The specialised structures in lichens for vegetative reproduction are .... , and ..... .

ii) The dark-coloured gall-like outgrowths of lichen thallus that can give rise to new thalli are called ..... .

iii) The cylindrical finger-like outgrowths on the lichen thallus that give rise to new thalli are called ..... .

iv) The asexual spores produced in lichens may be ..... , ... or .....

v) The sexual reproduction in ascolichens is similar to ..... .

d) In the following sentences fill in the blank spaces with appropriate words.

i) Lichens can survive temperature as high as ..... .

ii) Lichens are slow-growing. They may grow at the rate of about ..... per year.

iii) In Arctic regions lichen thalli as old as ..... years are found.

iv) Lichens are sensitive to pollutants like ..... and ..... elements ..... and caesium.

v) The lichen commonly known as moss reindeer is eaten by reindeer, caribou and sheep is ..... .

e) Indicate which of the following statements are true or false with regards to lichens.
   i) In some lichens when algal cells are penetrated by fungal haustoria they get killed.
   ii) In lichens the algal partner provides carbon compounds to the fungal partner.
   iii) Sexual reproduction in ascolichen is similar to that of ascomycetes fungi.
   iv) The fungal partner provides food and water to the algal partner.
   v) In some lichens *Anabaena* is the algal partner.

11.3 MYCORRHIZA

Mycorrhiza is a mutualistic symbiotic association between fungi and roots of a plant. German botanist Albert Bernhard Frank in 1885 introduced the term "*Wurzelpilze*" (Root fungi). Literally it means tree nutrition via fungi. Some other terms to relate this relationship are "*Wurzelpilze*", mycorhiza, Mykorhiza. However, the spelling "*mycorrhiza*" is commonly used. It means 'fungus-root'. Presumably, the relationship has developed very early in the process of colonisation of terrestrial environment about 600-450 million years ago. Almost 95 per cent of vascular plants have mycorrhizal associations. There are more than 6000 fungi reported to be capable of forming mycorrhizal association. During the relationship the fungus provides mineral nutrients, principally, phosphorus to the plants and gets photosynthetic sugar and vitamins in return. In this Section you shall learn the morphological characteristics, physiological and ecological significance of two principle kinds of mycorrhizae: *ectomycorrhiza* and *endomycorrhiza*.

A few non-mycorrhizal plants are *Juncus*, *Carex*, *Silene*, *Brassica napus*.

11.3.1 Ectomycorrhiza

Ectomycorrhiza represents most advanced kind of mutualistic, symbiotic relationship between higher plants and fungi. In this kind of mycorrhiza, the root system of the plant is completely surrounded by a sheath (could be several mm thick) of 'fungal tissue'. Only about 3 per cent of seed plants have ectomycorhizal association. In majority of these seed plants of forest trees inhabiting both temperate and tropical regions representing 140 genera belonging to 43 families, occur in Northern Hemisphere. They include *Pinus*, *Picea*, *Abies*, *Populus*, *Salix*, *Fagus* (Fig. 11.6), *Betula*, and *Quercus*. *Eucalyptus* and *Nothofagus* are important trees, with ecto-mycorrhizal association belonging to Sourthern hemisphere.

The characteristics of an ectomycorrhiza are:

- presence of substantially thick fungal tissue around plant roots;
- these roots that get surrounded with fungus are shorter and wider than unsurrounded roots;
- the hyphae penetrate between the inter-cellular spaces of outer-most cell layers of the root, the fungus forms a network of hyphal filaments (hyphae, strands and rhizomorph);
- these hyphae extend into the soil for mineral exploration; and
- these intercellular hyphae form a 'net-like' structure called *Hartig net*.

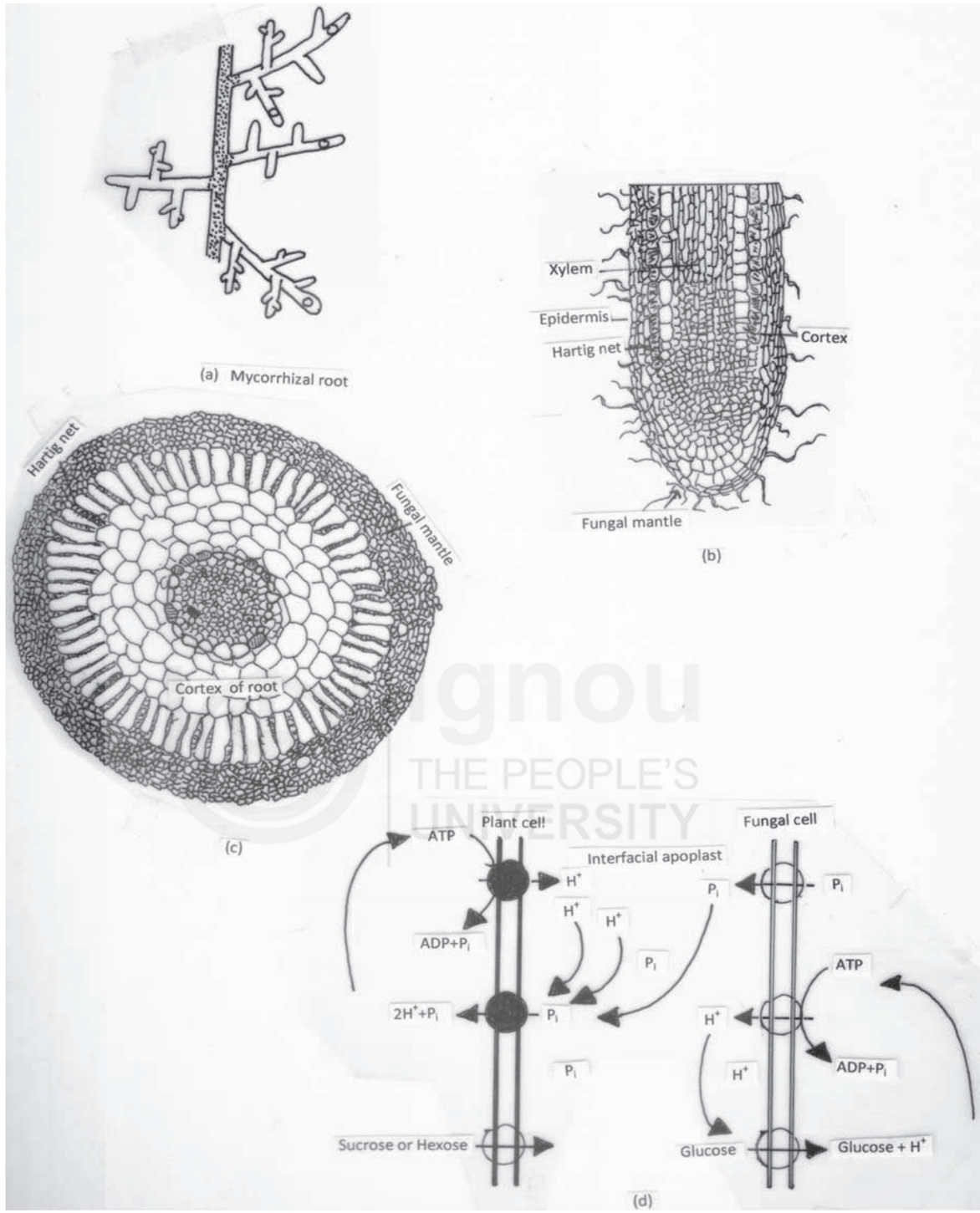


Fig. 11.6 : Ectomycorrhiza: a) *Fagus* sp., a portion of root with highly branched mycorrhizae; b) L.S. of root tip showing ectomycorrhizae; c) T.S. of a mycorrhizal root showing the fungal mantle and the intercellular hyphae between the outermost root cells, known as Hartig net; d) A diagrammatic representation of a model for the exchange-transfer of phosphate and carbon compounds across the arbuscular mycorrhizal interface. ATPases and secondary transporters are localized in the membranes of the arbuscular interface. These are shown by circles with arrows indicating direction of transport. Credits: (a,c) Ingold & Hudson 1993, (b) Sethi & Walia, 2011 and (d) Moore et al., 2011.

About 65 genera and upto 6000 fungal species are reported to be in ectomycorrhizal association. Two third of these species belong to Division Basidiomycota, while the rest are members of Division Ascomycota. So far, the genus *Endogyne* is the sole representative of Division Zygomycota that forms ectomycorrhiza.

The fungus to tree relationship could be very interesting:

- *Boletus* spp. and *Tricholoma* spp. (both members of Basidiomycota) are highly host-specific since they form ectomycorrhizal relationship with *Larix* only;
- In contrast, the species belonging to genus *Amanita* (woodland-mushroom) has non-specific symbiotic associationship with more than 20 kinds of forest trees,
- On the other hand, a pine tree can have an association with more than 40 different kinds of fungal species to have an ectomycorrhizal association.

Host-Fungus Relationship

Ectomycorrhiza depends on host for C-nutrient (products of photosynthesis). Only a few ectomycorrhiza can utilise cellulose/lignin as C-source while living as independent saprobes. In return the fungus helps hosts in mineral-ions-uptake especially those of ions of phosphate and ammonium. The fungus efficiently utilises the organic compounds such as polypeptides and nucleic acids in the soil as a source of nitrogen and phosphorus respectively. The host plant is incapable of such direct utilisation. It has been observed that pine like most other host plants, when deprived of ectomycorrhiza fail to grow or grow very slowly.

11.3.2 Endomycorrhiza

In endomycorrhiza the fungal structures are almost entirely present within the host root. Outwardly such roots look normal. Arbuscular mycorrhiza (AM) an example of endomycorrhiza are the commonest of all mycorrhizae. They are observed in more than 80 per cent of plant species of which more than 90 per cent are vascular plants. The majority of them being crop-plants and are absent in families: Brassicaceae, Caryophyllaceae, Chenopodiaceae and Urticaceae.

The fungal-host association in endotrophic AM was earlier known as Vesicular Arbuscular Mycorrhiza (VAM). However, the term VAM has been dropped in the favour of term AM (Arbuscular Mycorrhiza). Widely believed to be the most ancient and most common, the genus *Glomus*, Order Glomales; Division Zygomycota (many mycologists place *Glomus* in an independent Division Glomeromycota) is an example of the AM fungi. Some other genera belonging to order Glomerales which are AM fungi are *Gigaspora, Scutellospora*, *Acaulospora*, and *Entrophospora.* The genus *Paraglomus* (Order Paraglomales) and genera *Geosiphon* and *Archaespora* (Order Archaesporales) are also AM fungi.

Endomycorrhiza can be classified as:

1) Arbuscular endomycorrhiza;

2) Ericoid endomycorrhiza; and

3) Orchidaceous endomycorrhiza.

***Arbuscular endomycorrhiza* (AM)**

- AM-fungi are obligate biotrophs, i.e., they can survive only within the host-cells.
- They occur as coarse, intercellular, aseptate, coenocytic mycelium.
- The repeated, dichotomous branching of hyphae is called Arbuscule (Fig. 11.7 and 11.8).
- Within host tissue they form large balloon-shaped, intercalary or terminal thick-walled vesicles.
- The arbuscules invaginates plasmalemma of host cells. Thus, these can be termed as haustoria.
- The plant and fungal cell membranes are separated by an apoplastic compartment called periarbuscular space.
- In this space the nutrient exchange takes place.
- Each arbuscule has a short life-span of 4-15 days.
- The dead arbuscules are digested by host cells. These are observed as irregular clumps of fungal remains within host cells (Fig. 11.7).
- These vesicles are swollen, spherical or oval, multinucleate structures of about >100µm in diameter.
- These vesicles are rich in lipid-content.
- Asexual reproduction is very common. It is by budding of hyphal tips. Mycelium when comes into contact with soil develops into multinucleate chlamydospores. These associate with new plant roots. They are also called resting spores.

  Resting spores can be harvested from the soil. They can be transferred to new non-specific host of land plants. They can get associated with female gametophytes of Bryophyta and Pteridophyta.
- Sexual reproduction is not reported in *Glomus*.

Host-AM relationships

- AM fungus obtains reduced C from the host.
- Host cells get in turn the phosphates mobilised by AM fungus through exploration of soil microhabitat.

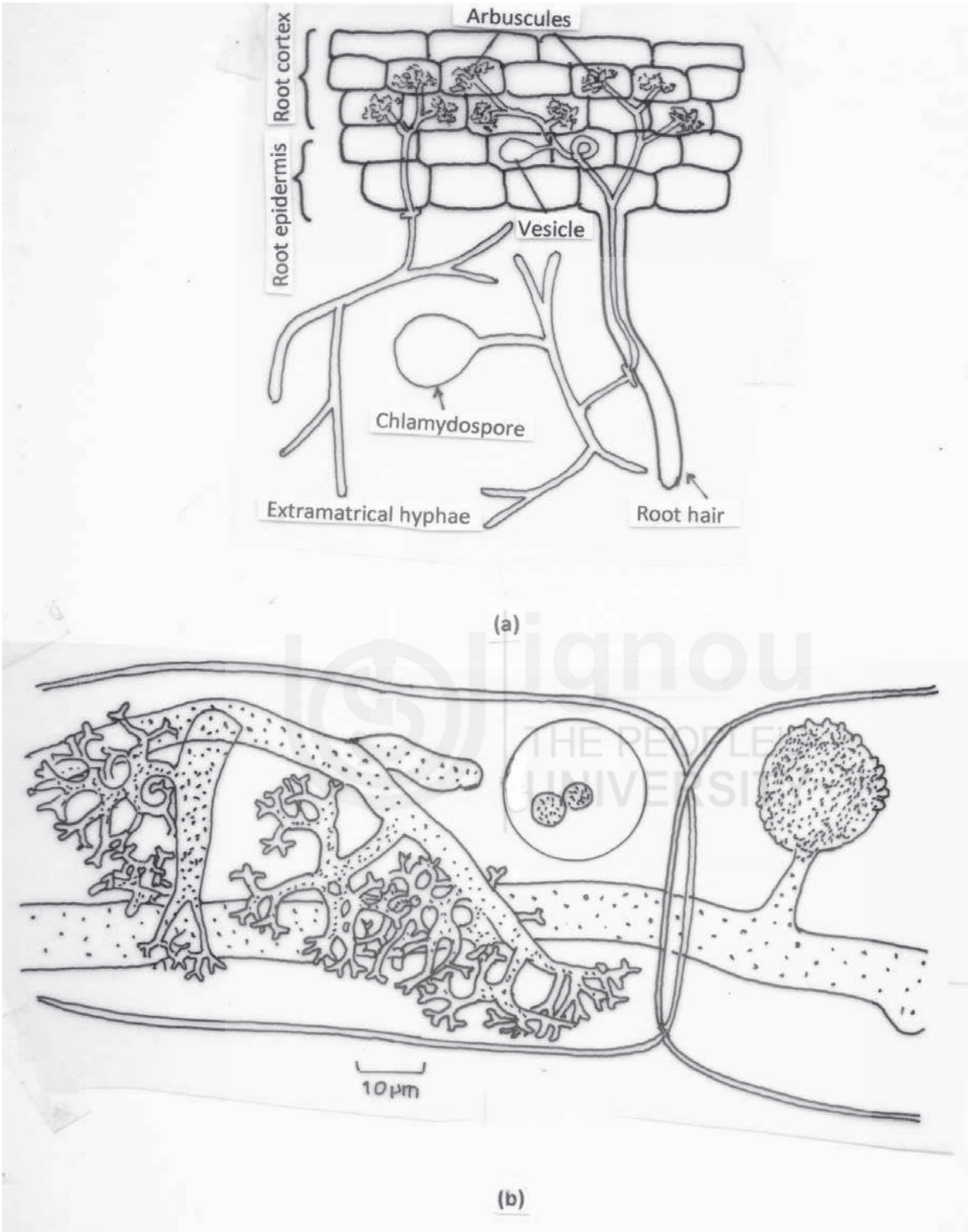


Fig. 11.7: Arbuscular endomycorrhiza : a) Diagrammatic representation of cellular features. Hyphae from the germinating chlamydospore enter a root hair, grow within it, enter cortical cells and form arbuscules. These are finely branched clusters of hyphae, which are the major sites of nutrient exchange between fungus and plant; b) Parts of two root cells of onion with vesicular arbuscular endomycorrhiza – *Glomus mosseae*. The cell on the left hand has two nucleoli and a branched haustorium or arbuscules. The cell on the right hand shows degenerated arbuscule. Credits: (a) Redrawn from Moore et al., 2011, (b) Webster & Weber, 2007.

Box No. 11.1: Reserve mycorrhizal relationship.

The AM fungus *Geosiphon pyriformis* (order: Archaesporales) is in a unique symbiotic partnership with a Cyanobacterium, *Nostoc punctiforme*. In this relationship the photobiont (*Nostoc*) is harboured in bladders of the fungus. These bladders are up to 2 mm in size. The fungus here is a macrosymbiont as well as exhabitant. The cyanobacterium, *Nostoc*, the photosynthetic partner, is microsymbiont, as well as inhabitant. This situation is reverse of other AM fungi-host relationship wherein the photobiont is macrosymbiont and the AM-fungus is microsymbiont.

Ericoid endomycorrhiza

The fungus *Hymenoscyphus ericae* (an Ascomycota) has endomycorrhizal relationship with the genera *Erica*, *Calluna*, *Vaccinium* and some plants of mountain moorlands and low-land heaths. The fungus helps the plant in nitrogen and phosphate uptake. The fungus makes nitrogen available by breaking down the polypeptides present in the soil. The fungus in return gets C-photosynthate from the plant (Fig. 11.9).

During unfavourable harsh season of winter when the host plant is unable to do photosynthesis the fungus supports them by providing C-nutrients by digesting of polypeptides. Association of fungi with non-chlorophyllous genus *Monotropa* from monotropoid ericoid endomycorrhiza. Arbutiod mycorrhiza is another Sub-section of ericoid endomycorrhiza.

Orchidaceous endomycorrhiza

Almost all the members of the family Orchidaceae appear to be associated with Orchidaceous endomycorrhiza throughout all the stages of their life cycle. In this relationship there is net flow of sugars (C-nutrient) from the fungal partner to the plant at least during the establishment of seedling-stage of orchids.

The orchid 'seeds' are very small and are without any differentiation. They possess no food reserve. They germinate into a specialized structure protocorm. This protocorm can germinate only if provided with C-nutrient source. In nature, a mycorrhizal association makes the C-nutrient available to these protocorms. The fungus, *Rhizoctonia* spp. (chiefly: *R. solani* and *R. cerealis*) infect orchid protocorm through its epidermal hair or through suspensor cells. The fungus invades epidermis of protocorm and enters cortical cells wherein it invaginates plasmalemma to produce a dense mass of coiled hyphae. This structure is called **peloton**. The peloton is ensheathed by host plasmalemma to form a perifungal membrane. These membranes are modified plasmalemma. The nutrients enter the host through these modified plasmalemma. Thus, the fungus nourishes the host. So, in such an Orchidaceous endomycorrhizal relationship plant parasitizes on the fungus *Rhizoctonia*.

Interestingly, the same fungus *Rhizoctonia* is a pathogen of a large number of non-orchid crop plants.

Certain mycorrhiza that enter into symbiotic relationship with *Pinus*, *Picea* and *Larix* exhibit the characters of both the ecto- and endo-mycorrhiza. They are described as *ecto-endomycorrhiza.* Fig. 11.9 illustrates various categories of mycorrhiza. Some of the examples have been described above and the additional examples and information would help you to understand mycorrhiza in a comprehensive manner.

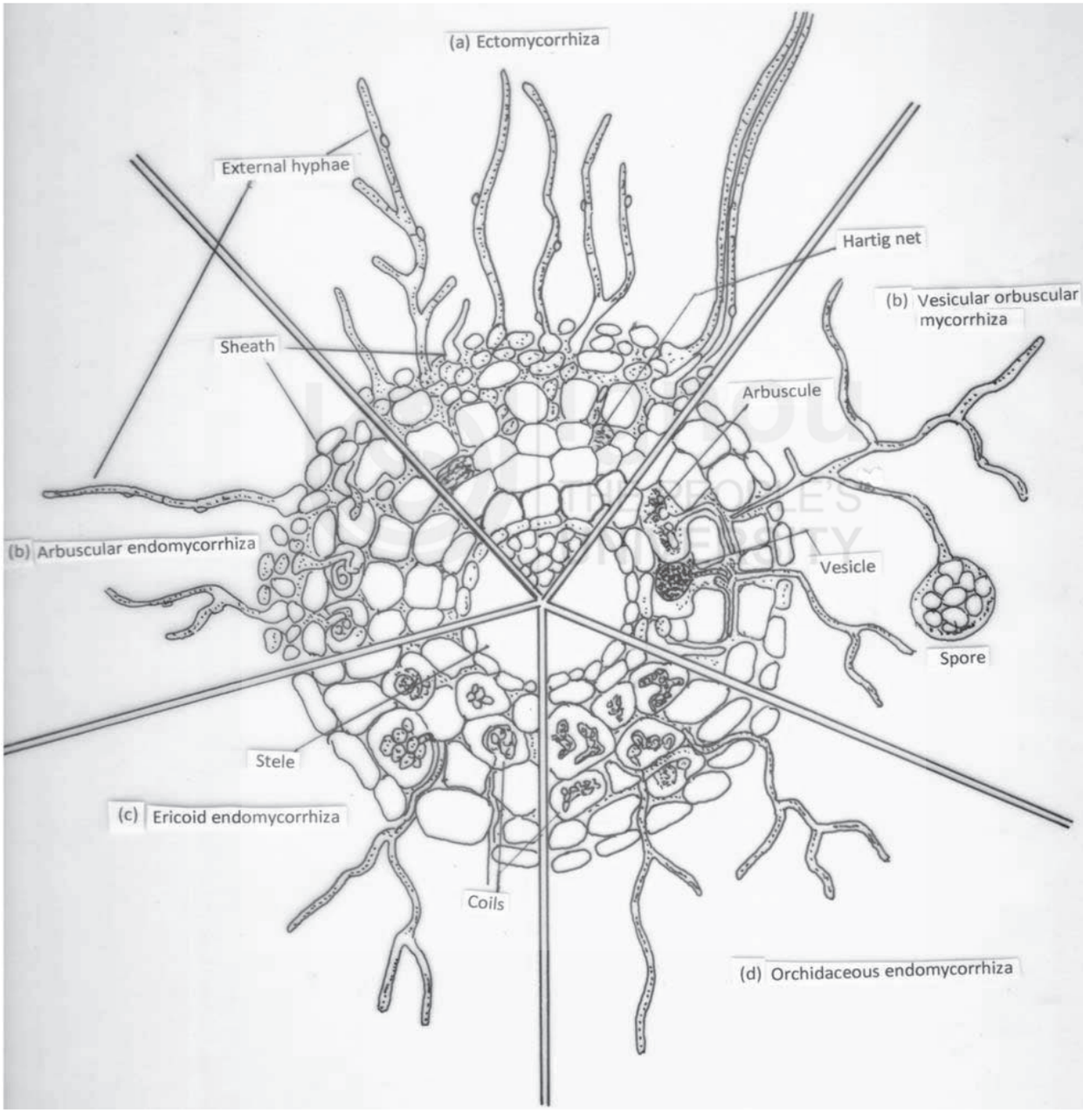


Fig. 11.8: Ecto- and endo-mycorhizae in transverse section of root.

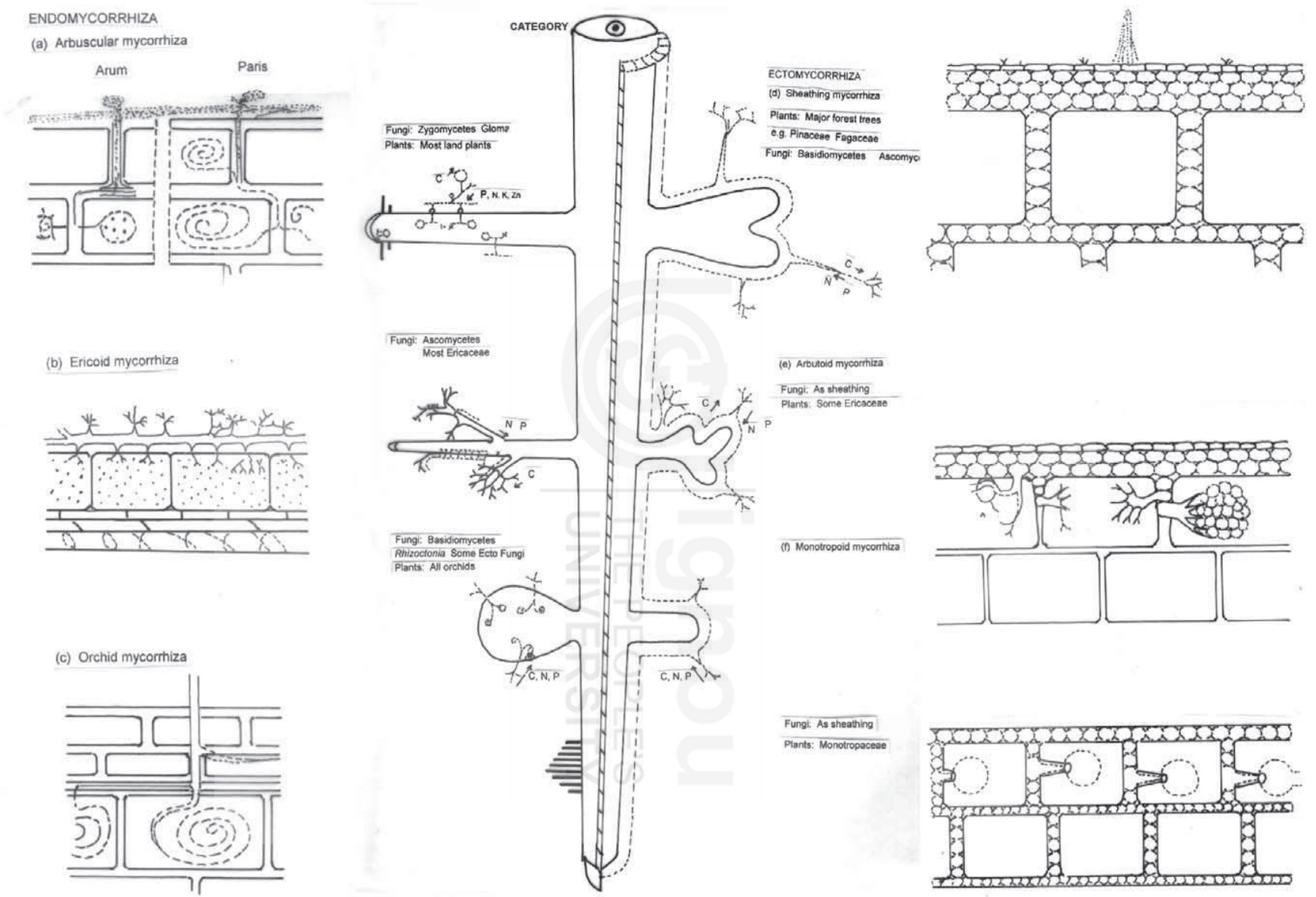


Fig. 11.9 : Diagrammatic representation of ecto- and endo-mycorhizae. The characteristic aspects of the fungal structures, the nature and direction of movements of nutrients are also indicated in the illustrations. The symbols used are: C, carbon (sugar); N, nitrogen; P, phosphorous, K, potassium, Zn, zinc. The sizes of the letters C, N, P, K and Zn denote the relative importance of the nutrient transfer process in the particular mycorrhizal type. This figure is redrawn from *Handbook of Plant Science, 2007, John Wiley & Sons Ltd.*

11.3.3 Ecological Significance

Mycorrhiza play a significant role in survival of not only the host they are in partnership with, but also to the ecology of the soil where they are present.

Let us study some of these beneficial contributions of mycorrhiza.

Host-specific Benefits

Mycorrhiza helps hosts:

- by making nutrients available to host either by inhabiting the host or through presence in the physiologically active area of root growth;
- increases the ability of plant to capture water and nutrients, especially N, P, K, Ca from soil;
- increases tolerance to drought, high soil-heat, and extreme soil acidity;
- provides protection from certain pathogenic fungi and nematodes that attack roots;
- induces hormonal relationship that cause feeder roots to remain physiologically active for long period of time;
- increase growth rate, dry weight, mineral-content of the host; and
- improves water relations of the host plant.

Non-host Specific Benefits

Some of the prominent non-host specific benefits of mycorrhiza are:

- Improve nutritional deficiencies of sand-dunes, recently disturbed soils, soil heaps and areas covered with volcanic ash. This is achieved by successful colonisation of these soils by plants associated with roots infected with members of order Glomales;
- Mycorrhiza fungi link plants together into communities that are more resilient to stress, disturbances than single plant;
- Help transfer nutrients between two different plants which are connected with a common mycorrhizal system;
- Mycorrhizal interconnections in the soil forms a network of:
  - Plant-to-plant
  - Plant-to-fungus
  - Fungus-to-plant
- Help natural ecosystem via seedling establishment, altering plant-plant interaction; and
- Supply recycled nutrients.

The cell walls of fungal hyphae and spores of AM fungi *Glomus* produced abundant quantity of a cell-wall protein 'glomalin'. This protein permeates into the soil. By some estimates it is suggested that glomalin accounts of 30 per cent of total carbon in soil. The glomalin help in forming clumps of soil granules and add to the structure of soil.

Adequate soil aeration, moisture and suitable pH along with ambient air temperature and sunlight sufficient for photosynthesis by plants are some of the factors for mycorrhizal association to flourish.

SAQ 2

a) Fill the blanks spaces in the following statements with appropriate words:

i) *Endogyne* is the sole representative of the Division ..... in mycorrhizal associations.

ii) The more acceptable term for VAM fungi is ..... .

iii) In orchidaceous endomycorrhiza the fungus ..... nourishes the host.

iv) AM fungi are obligate ..... .

v) Roots of more than 80 per cent of species have ..... mycorrhizal association.

b) Tick the correct alternatives from the choices provided in the brackets in the following statements:

i) Host-fungal association in mycorrhiza is (symbiotic / parasitic).

ii) Hartig net produced by fungal hyphae is characteristic of (ecto- / endo-) mycorrhiza.

iii) More than two-thirds of fungal species that enter into mycorrhizal association belong to the division (Ascomycota / Basidiomycota).

iv) Arbuscles are formed in (ecto- / endo-) mycorrhiza.

v) Chlamydospores produced by fungus *Glomus* during reproduction in a mycorrhiza are (sexual / asexual) propagules.

11.4 SUMMARY

- In lichens, the heterotrophic non-photosynthetic fungi form symbiotic association with green algae or blue-green algae and constitute new thalli. The green-thallus thus formed has no resemblance to either fungus or an alga growing separately.
- Lichens can be identified by their striking colours and distinct growth forms. Lichen thallus consists of interwoven hyphae which shelter algal cells and derive nutrition from them. If the algal partner is a cyanobacterium, it provides the fungal partner with nitrogen nutrition in addition to photosynthates.
- Lichens reproduce by special vegetative reproductive structures – soredia, isidia or cephalodia. The asexual spores formed are oidia, pycniospores and conidia. In ascolichens sexual reproduction also takes place and it is similar to the fungi belonging to Ascomycota.
- Lichens are ecologically important and pioneer vegetation. They can colonise harsh habitats.

- Lichens are eaten by arctic animals. In some countries they are used as food for humans. Dyes and some other chemicals were formerly extracted from lichens. Lichens are also used for medicinal purposes.
- Lichens are very sensitive to air pollutants and therefore can be used as indicators of pollution for the area where they grow.
- Mycorrhiza are mutualistic symbiotic association between a fungus and plant root. They are classified as ectomycorrhiza and endomycorrhiza depending upon whether the fungal component is peripheral to root or infillrate the outer root tissues.
- Almost all the fungi that form mycorrhizal associations belong to Division Basidiomycota (about two third) and Ascomycota members constitute one third.
- Roots of almost 90 per cent of plant species enter into endomycorrhizal association with fungi.
- During such relationship fungi provides minerals especially P and N, and vitamins to the host and get carbon products of photosynthesis in return.
- Harting-nets formed by fungi in the ectomycorrhiza help the exchange of material between and host-tissues and fungal mycelia.
- Ericoid, arbuscular and orchidaceous mycorrhiza belong to the category – endomycorrhiza. Arbuscules, peloton are the principle structures involved in transfer of nutrients between root tissues and fungal mycelia.
- Adequate soil aeration, soil moisture, suitable pH range, healthy ambient air temperatures, adequate sunlight for photosynthesis in host-all helps good mycorrhizal relationship.

11.5 TERMINAL QUESTIONS

1. Give an example of each of the following morphological types of lichen.
   i) Crustose, ii) Foliose, iii) Fructose.
2. Write the various uses of lichens under the headings – food, medicine, and dyes.
3. Explain the role of lichens as pioneers of vegetation.
4. Enumerate the characteristics of an ectomycorrhiza.
5. Explain the salient features of orchidaceous endomycorrhiza.

11.6 ANSWERS

Self-Assessment Questions

1. a) i) Mycobiont, phycobiont/photobiont
   ii) Ascomycota
   iii) green alga, cyanobacteria
   iv) cortex, medulla

v) *Trebouxia*, *Trentepohlia*

vi) *Nostoc*

b) i) F, ii) T, iii) T, iv) F, v) T

c) i) Soredia, isidia, cephalodia

ii) cephalodia

iii) isida

iv) oidia, conidia, pycniospores

v) Ascomycota

d) i) 50°C

ii) 1 mm

iii) 4500

iv) SO_2, radioactive, strontium

v) *Cladonia rangiferina*

e) i) F, ii) T, iii) T , iv) F, v) F

2. a) i) Zygomycota

ii) Arbuscular ectomycorrhiza or AM fungi

iii) *Rhizoctonia*

iv) biotrophs

v) endo-

b) i) symbiotic

ii) ecto-

iii) Basidiomycota

iv) endo-

v) asexual

Terminal Questions

1. See Subsection 11.2.1
2. See Subsection 11.2.3
3. When the lichens grow on bare rocks, by their activity weathering of rocks takes place. Consequently they build up organic debris which is necessary for the growth of vegetation.
4. See Subsection 11.3.1
5. See Subsection 11.3.2

11.7 GLOSSARY

Arbuscule : Repeated dichotomous branching of hyphae of endomycorrhiza within the host tissue.

Cephalodium (pl. cephalodia) : Dark-colured gall-like outgrowths of lichen thallus that serve as vegetative propagules for reproduction.

Ectendomycorrhiza : Mycorrhiza that exhibit characters of both ecto- and endo-mycorrhiza.

Ectomycorrhiza : Mycorrhiza that surrounds a host root in the form of sheath, strand or rhizomorph.

Endomycorrhiza : Mycorrhiza that are almost entirely present within host root.

Harting-net : Inter-cellular hyphae of ectomycorrhiza that form net-like structure.

Isidum (pl. isidia) : Cylindrical finger-like outgrowths on lichen thallus that serves as vegetative propagule for reproduction.

Mycobiont : The fungal component of a lichen.

Peloton : A dense mass of coiled hyphae formed after invagination of orchid protocorm cortical cells by Orchidaceous endomycorrhiza.

Phycobiont : The algal-component of a lichen.

Protocorm : Post-'seed' germination structure produced by orchid.

Soredium (pl. soredia) : Algal cells surrounded by fungal hyphae to serve as vegetative propagule for reproduction.

11.8 FURTHER READING

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