BIOLOGY OF EUKARYOTIC MICROBES

M.Sc. MICROBIOLOGY

SEMESTER-I, PAPER-IV

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BIOLOGY OF EUKARYOTIC MICROBES

First Edition : 2025

No. of Copies :

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Published by:

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Acharya Nagarjuna University

Printed at:

FOREWORD

Since its establishment in 1976, Acharya Nagarjuna University has been forging ahead in the path of progress and dynamism, offering a variety of courses and research contributions. I am extremely happy that by gaining 'A+' grade from the NAAC in the year 2024, Acharya Nagarjuna University is offering educational opportunities at the UG, PG levels apart from research degrees to students from over 221 affiliated colleges spread over the two districts of Guntur and Prakasam.

The University has also started the Centre for Distance Education in 2003-04 with the aim of taking higher education to the door step of all the sectors of the society. The centre will be a great help to those who cannot join in colleges, those who cannot afford the exorbitant fees as regular students, and even to housewives desirous of pursuing higher studies. Acharya Nagarjuna University has started offering B.Sc., B.A., B.B.A., and B.Com courses at the Degree level and M.A., M.Com., M.Sc., M.B.A., and L.L.M., courses at the PG level from the academic year 2003-2004 onwards.

To facilitate easier understanding by students studying through the distance mode, these self-instruction materials have been prepared by eminent and experienced teachers. The lessons have been drafted with great care and expertise in the stipulated time by these teachers. Constructive ideas and scholarly suggestions are welcome from students and teachers involved respectively. Such ideas will be incorporated for the greater efficacy of this distance mode of education. For clarification of doubts and feedback, weekly classes and contact classes will be arranged at the UG and PG levels respectively.

It is my aim that students getting higher education through the Centre for Distance Education should improve their qualification, have better employment opportunities and in turn be part of country's progress. It is my fond desire that in the years to come, the Centre for Distance Education will go from strength to strength in the form of new courses and by catering to larger number of people. My congratulations to all the Directors, Academic Coordinators, Editors and Lesson-writers of the Centre who have helped in these endeavors.

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M.SC. MICROBIOLOGY
SEMESTER-I
104MB24 - BIOLOGY OF EUKARYOTIC MICROBES

UNIT-I

Ultra structure of eukaryotic cell; Organelles of eukaryotic cell - Ultrastructure of Cell wall, Cell membrane, Nucleus, Chloroplast, Mitochondria, Endoplasmic reticulum, Ribosome, Golgi apparatus, Lysosomes.

UNIT-II

Phases of cell cycle, role of check points in monitoring and regulation of cell cycle, Kinenins. Cell division - different stages of mitosis and meiosis. Cytoskeleton - definition, types and structure of cytoskeletal filaments, role of cytoskeleton in cell division.

UNIT-III

Algae - Distribution, General account, Thallus organization, nutrition, reproduction and classification of algae. Economic importance of algae - Algae as primary producers and commercial products. Algae as SCP. Algal blooms and toxins.

UNIT-IV

Fungi - General characters, Nutrition (parasitic, saprophytic & symbiotic), Reproduction, Parasexuality. Ainsworth's system of classification. Importance of fungi in Agriculture and Industry. Importance of yeasts. Edible and poisonous mushrooms. Mycotoxins.

UNIT-V

Protozoa - General account, morphology, nutrition and locomotion.Brief account of - Entamoeba, Trypanosoma, Leishmania, Trichomonas, Giardia, Balantidium and Pneumocystis.

REFERENCE BOOKS:

1) Introductory Phycology - HD Kumar
2) Biology of Algae -Round
3) The Fungi - Alexopolus
4) Prescott et al-Microbiology
5) Barner R.D - Invertebrates Zoology

104MB24

CENTRE FOR DISTANCE EDUCATION

ACHARYA NAGARJUNA UNIVERSITY

M.Sc. Degree Examination

MICROBIOLOGY- I SEMESTER

Model Question Paper

BIOLOGY OF EUKARYOTIC MICROBES

Time: 3 hours **Maximum Marks: 70**

Answer ALL Questions **(5x14 = 70 marks)**

UNIT-I

1. a) Give a brief account on overall ultrastructure of Eukaryotic cell.

OR

b) Explain the morphological features and functions of Eukaryotic Chloroplast and Mitochondria.

UNIT-II

2. a) Write an account on different phases of eukaryotic cell cycle.

OR

b) Describe the different stages of mitotic cell division.

UNIT-III

3. a) Give an account on thallus organization and nutrition modes in algae.

OR

b) Explain the economic importance of algae.

UNIT-IV

4. a) Write an account on general characters and reproduction modes of fungi.

OR

b) Describe the Ainsworth's system of fungal classification.

UNIT-V

5. a) Give an account on general characters of Protozoa.

OR

b) Describe in brief about *Entamoeba* and *Trypanosoma* genera of protozoa.

CONTENTS

LESSON – 1

ULTRA STRUCTURE OF EUKARYOTIC CELL, CELL WALL AND CELL MEMBRANE

OBJECTIVE OF THE LESSON

Students will understand the internal structure of cell and brief notes on various cell organelles. Apart from this students came to know the role of cell wall and plasma membrane in protecting the cell and its internal components.

STRUCTURE OF THE LESSON

1.1 INTRODUCTION

The biological science which deals with the study of structure, function, growth and reproduction along with molecular organization is called cytology (Gr., *kytos* = hollow vessel or cell; *logous* = to discourse) or cell biology. The body of all living organisms except viruses has cellular organization and may contain one or many cells. The organisms with single cell are called unicellular organisms (e.g., bacteria, blue green algae, some algae, Protozoa, etc.). The organisms with many cells in their body are called multicellular organisms (*e.g.,* most plants and animals). Cells are of two types based on the presence or absence of nuclear membranes: A. Prokaryotic cells B. Eukaryotic cells. The prokaryotic (Gr., *pro* = primitive or before; *karyon* = nucleus) are small, simple and most primitive. The eukaryotic cells (Gr.,

eu=good, *karyotic*=nucleated) are having nuclear membrane around the chromatin material. The eukaryotic cells are the true cells which occur in the plants (algae to angiosperms) and the animals (Protozoa to mammals).

The plant cell is always surrounded by a cell wall and this feature distinguishes them from animal cells. The cell wall is a non-living structure which is formed by the living protoplast. In most of the plant cells, the cell wall is made up of cellulose, hemicellulose, pectin and protein. In many fungi, the cell wall is formed of chitin and in bacteria, the cell wall contains protein-lipid-polysaccharide complexes.

Plasma membrane encloses every type of cell, both prokaryotic and eukaryotic cells. Plasma membrane is an ultrathin, elastic, living, dynamic and selective transport-barrier. It is a fluid-mosaic assembly of molecules of lipids (phospholipids and cholesterol), proteins and carbohydrates. Plasma membrane controls the entry of nutrients and exit of waste products, and generates differences in ion concentration between the interior and exterior of the cell. It also acts as a sensor of external signals and allows the cell to react or change in response to environmental signals.

1.2 ULTRA STRUCTURE OF EUKARYOTIC CELL

1.2.1 Cellular Components

A eukaryotic cell is a complex structure having true nucleus and cell organelles along with large number of proteins, enzymes and minerals. The eukaryotic cell contains the following components.

Cell Wall and Plasma Membrane: The outermost structure of most plant cells is a dead and rigid layer called cell wall. It is mainly composed of carbohydrates such as cellulose, pectin, hemicellulose and lignin and certain fatty substances like waxes. There is a pectin-rich cementing substance between the walls of adjacent cells which is called middle lamella. The cell wall which is formed immediately after the division of cell, constitutes the primary cell wall. Primary cell wall is composed of pectin, hemicellulose and loose network of cellulose microfibrils. In certain types of cells such as phloem and xylem, an additional layer is added to the inner surface of the primary cell wall at a later stage. This layer is called secondary cell wall and it consists mainly of cellulose, hemicellulose and lignin. In many plant cells, there are tunnels running through the cell wall called plasmodesmata which allow communication with the other cells in a tissue. Every kind of animal cell is bounded by a living, extremely thin and delicate membrane called plasmalemma, cell membrane or plasma membrane. In plant cells, plasma membrane occurs just inner to cell wall, bounding the cytoplasm. The plasma membrane is a three layered structure. The plasma membrane is a selectively permeable membrane and it selectively permits the entry or exit of materials.

Cytoplasm: The plasma membrane is followed by the colloidal organic fluid called matrix or cytosol. The cytosol is the aqueous portion of the cytoplasm also known as the extra nuclear protoplasm) and of the nucleoplasm. The cytosol serves to dissolve the great variety of molecules concerned with cellular metabolism, e.g., glucose, amino acids, nucleotides, vitamins, minerals, oxygen and ions. The cytosol of cells also contains fibers that help to maintain cell shape and mobility, these fibers are termed as the cytoskeleton.

Endoplasmic Reticulum (ER): The cytoplasm of the contains an extensive network of membrane limited channels called endoplasmic reticulum (or ER). Some portion of ER membranes remains continuous with the plasma membrane and the nuclear envelope. The

outer surface of rough ER has attached ribosomes, whereas smooth ER does not have attached ribosomes. Functions of smooth ER include lipid metabolism, glycogenolysis and drug detoxification. On their membranes, rough ER (RER) contain certain ribosome specific, transmembrane glycoproteins, called ribophorins I and II, to which are attached the ribosomes while engaged in polypeptide synthesis.

Golgi Apparatus: It is a cup-shaped organelle which is located near the nucleus. Golgi apparatus consists of a set of smooth cisternae present in stacks in parallel rows. It is surrounded by spherical membrane bound vesicles which appear to transport proteins. Plant cells contain many freely distributed sub-units of Golgi apparatus, called dictyosomes, secreting cellulose and pectin for cell wall formation during the cell division.

Lysosomes: The cytoplasm of animal cells contains many tiny, spheroid or irregular-shaped, membrane-bounded vesicles known as lysosomes. The lysosomes are originated from Golgi apparatus and contain numerous hydrolytic enzymes for intracellular and extracellular digestion. Lysosomes have a high acidic medium (pH 5) and this acidification depends on ATP- dependent proton pumps. The lysosomes of plant cells are membrane-bounded storage granules containing hydrolytic digestive enzymes, E.g. vacuoles of parenchymatous cells.

Cytoplasmic Vacuoles: The cytoplasm of many plant and some animal cells (*i.e.*, ciliate protozoans) contains numerous small or large-sized, hollow, liquid-filled structures, the vacuoles. These vacuoles are supposed to be greatly expanded endoplasmic reticulum or Golgi apparatus. The vacuoles of animal cells are bounded by a lipoproteinous membrane and their function is the storage, transmission of the materials and the maintenance of internal pressure of the cell. The vacuoles of the plant cells are bounded by a single, semipermeable membrane known as tonoplast. These vacuoles contain water, phenol, flavonols, anthocyanins, alkaloids and storage products, such as sugars and proteins.

Peroxisomes: These are tiny circular membrane bound organelles containing a crystal-core of enzymes i.e., urate oxidase, peroxidase, D-amino oxidase and catalase. These enzymes are required by peroxisomes in detoxification activity. Peroxisomes are also related with β-oxidation of fatty acids and and also in degradation of the amino acids. In green leaves of plants, peroxisomes carry out the process of photorespiration.

Glyoxysomes: These organelles develop in a germinating plant seed to utilize stored fat of the seed. Glyoxysomes consist of an amorphous protein matrix surrounded by a limiting membrane. The membrane of glyoxysomes originates from the ER and their enzymes are synthesized in the free ribosomes in the cytosol. Enzymes of glyoxysomes are used to transform the fat stores of the seed into carbohydrates by way of glyoxylate cycle.

Mitochondria: Mitochondria are oxygen-consuming ribbon-shaped cellular organelles of immense importance. Each mitochondrion is bounded by two unit membranes. The outer mitochondrial membrane resembles more with the plasma membrane in structure and chemical composition. Inner mitochondrial membrane is rich in many enzymes, coenzymes and other components of electron transport chain. Inner mitochondrial membrane gives out finger-like outgrowths (cristae) towards the lumen of mitochondrion and contains tennis-racket shaped F1 particles which contain ATP-ase enzyme for ATP synthesis. Mitochondria also contain in their matrix single or double circular and double stranded DNA molecules, called mt DNA and also the 55S ribosomes, called mitoribosomes. Since mitochondria can synthesize 10 per cent of their proteins in their own protein-synthetic machinery, they are considered as semi-autonomous organelles.

Plastids: Plastids occur only in the plant cells. They contain pigments and may synthesize and accumulate various substances. Plastids are of different types: 1. Leucoplasts - are colourless plastids lacking thylakoids and ribosomes. 2. Amyloplasts – produce starch. 3. Proteinoplasts - accumulate protein. 4. Oleosomes or elaioplasts - store fats and essential oils. 5. Chromoplasts - contain pigment molecules and are coloured organelles. Chromoplasts impart a variety of colours to plant cells, fruits and petals. Chloroplasts are a type of plastids contains chlorophyll pigment.

Chloroplasts: These involved in the process of photosynthesis. Chloroplasts have diverse shapes in green algae but are round, oval or discoid in shape in higher plants. Each chloroplast is bounded by two membranous envelopes. Chloroplast contains third system of membranes within the boundary of inner membrane, called grana. The grana form the main functional units of chloroplast and are present in the stroma matrix. Stroma contains a variety of photosynthetic enzymes and starch grains. Grana are stacks of membrane-bounded, flattened discoid sacs, arranged like neat piles of coins. They contain DNA, ribosomes and complete protein synthetic machinery.

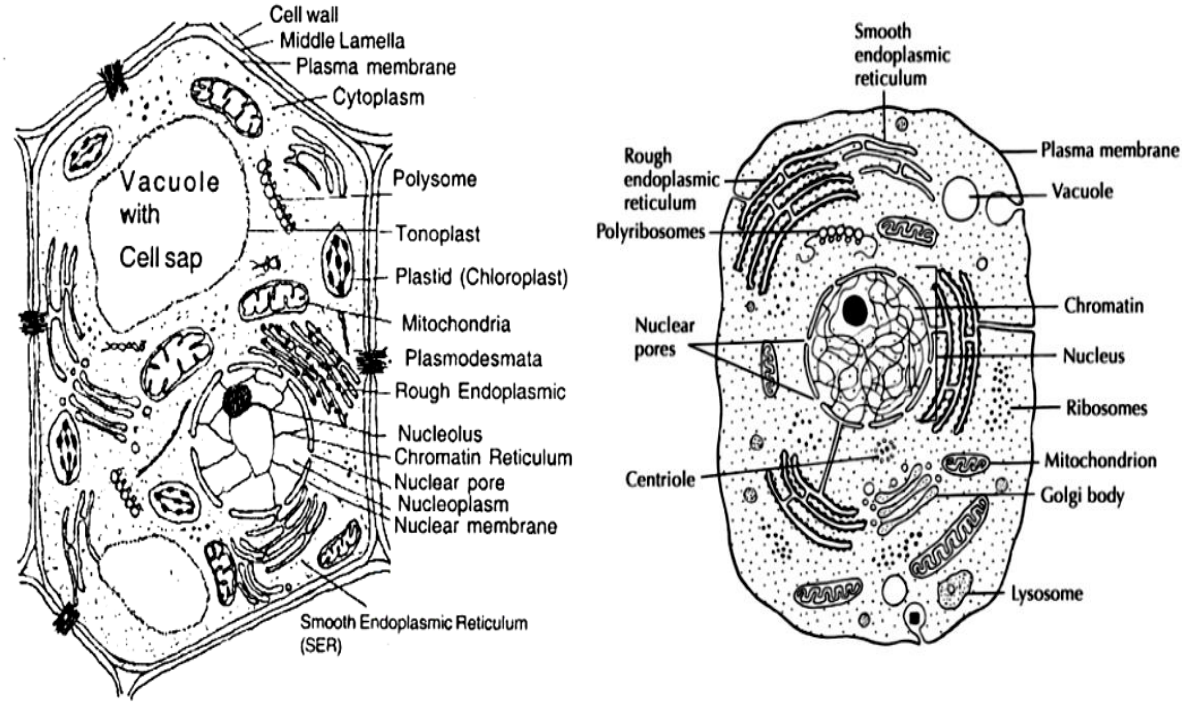
Ribosomes: Ribosomes are tiny spheroidal dense particles. Ribosome granules may exist either in the free state in the cytosol e.g. basal epidermal cells or attached to RER E.g.: pancreatic acinar cells, plasma cells, lymphocytes and osteoblasts. Ribosomes have a sedimentation coefficient of about 80S and are composed of two subunits namely 40S and 60S. The smaller 40S ribosomal subunit is prolate ellipsoid in shape and consists of one molecule of 18S ribosomal RNA and 30 proteins viz., S1, S2, S3, and so on. The larger 60S ribosomal subunit is round in shape and contains a channel through which growing polypeptide chain makes its exit. It consists of three types of rRNA molecules, viz., 28S rRNA, 5.8S rRNA and 5S rRNA, and 40 proteins.

Microtubules: Microtubules are found in the cytoplasm of all types of eukaryotic cells. They are long fibers about 24 nm in diameter. In cross section, the wall of a microtubule is made up of 13 globular subunits, called protofilaments, about 4 to 5 nm in diameter. Chemically, microtubules are composed of two kinds of protein subunits α-tubulin (tubulin A) and β-tubulin (tubulin B). The wall of a microtubule is made up of a helical array of repeating α and β tubulin subunits. Various cell organelles are derived from special assemblies of microtubules, which includes Cilia and flagella, Basal bodies and centrioles.

Nucleus: The nucleus is centrally located and spherical cellular component which controls all the vital activities of the cytoplasm and carries the hereditary material the DNA in it. The nucleus consists of 1. Chromatin – chromatin carries genes and is of two types, a) Euchromatin, which is well-dispersed form of chromatin which takes lighter DNA-stain and is genetically active b) Heterochromatin, which is the highly condensed form of chromatin which takes dark DNA-stain and is genetically inert. 2. Nuclear envelope and nucleoplasm - Nuclear envelope comprises two nuclear membranes i.e. an inner nuclear membrane which is lined by nuclear lamina and an outer nuclear membrane which is continuous with rough ER. At certain points the nuclear envelope is interrupted by structures called pores or nucleopores. Nuclear pores contain octagonal pore complexes which regulate exchange between the nucleus and cytoplasm. The nuclear envelope binds the nucleoplasm which is rich in those molecules which are needed for DNA replication, transcription, regulation of gene actions and processing of various types of newly transcribed RNA molecules (i.e., tRNA, mRNA and other types of RNA). 3. Nucleolus - Nucleus contains in its nucleoplasm a conspicuous, darkly stained, circular sub-organelle, called nucleolus. Nucleolus lacks any limiting

membrane and is formed during interphase by the ribosomal DNA (rDNA) of nucleolar organizer (NO). Nucleolus is the site where ribosomes are manufactured.

The ultrastructure of plant and animal cells is depicted in Figure 1.1.



Plant Cell **Animal Cell**

Figure-1.1: Ultra structures of plant cell and animal cell (https://tinyurl.com/4pprhhs5)

1.2.2 Functions of A Cell

Selective Permeability: Regulates the entry and exit of substances, allowing essential nutrients in and waste out.

Protection and Support: Acts as a barrier, protecting the cell from its surroundings and maintaining its structural integrity.

Cell Communication: Contains receptors that detect chemical signals (hormones, neurotransmitters) and initiate cellular responses.

Transport of Molecules: Facilitates movement through 1. Passive transport (diffusion, osmosis, facilitated diffusion – no energy required). 2. Active transport (requires energy, e.g., sodium-potassium pump). 3. Endocytosis (engulfing substances) and exocytosis (expelling substances).

Cell Recognition: Glycoproteins and glycolipids on the membrane help in immune recognition and interaction with other cells.

Cell Adhesion: Helps cells stick together to form tissues and communicate through junctions like tight junctions, gap junctions, and desmosomes.

Signal Transduction: Converts external signals into internal responses, influencing processes like growth, metabolism, and cell differentiation.

1.3 CELL WALL

1.3.1 Ultra Structure

The cell wall is a rigid and protective layer around the plasma membrane which provides the mechanical support to the cell. The cell wall also determines the shape of plant cells. Due to the shape of cell walls many types of plant cell as the parenchymatous, collenchymatous, etc., have been recognized.

Chemical Composition

Chemically, the plant cell wall is composed of a variety of polysaccharides (carbohydrates), lipids, proteins and mineral deposits, all exhibiting distinct staining reactions The polysaccharides of cell wall include cellulose, hemicelluloses, pectin compounds and lignins.

(1) Cellulose: It is a linear, unbranched polymer, consisting of straight polysaccharide chains made of glucose units linked by 1-4 β- bonds. These are the glucan chains which by intra-and intermolecular hydrogen bonding produce the structural units known as microfibrils, observable under electron microscopy and having toughness like the rubber. Each microfibril is ribbon-like flat fiber being 10 nm wide and 3 nm thick (or 25 to 30 nm in diameter) and is composed of about 2000 glucan chains in it. According to a classical estimate, each cellulose microfibril comprises three micelles or elementary fibrils: each elementary fibril contains about 100 cellulose molecules and each cellulose molecule is made up of 40 to 70 glucan chains (i.e., One microfibril = 3 × 100 × 70 = 21000 glucan chains). Often numerous microfibrils get associated to form the macrofibrils having up to 0.5 μm diameter and observable under the light microscopy. Cellulose is synthesized by a wide variety of cells that include bacteria, algae, fungi, cryptogams and seed plants.

(2) Hemicelluloses: These are short but branched heteropolymers of various kinds of monosaccharides such as arabinose, xylose, mannose, galactose, glucose and uronic acid. Some of the common hemicelluloses go under the names xylans, arabinoxylans, glucomannans, galactomannans and xyloglucans.

(3) Pectins: Pectins are water soluble, heterogeneous branched polysaccharides that contain many negatively charged D-galacturonic acid residues along with D-glucuronic acid residues. Because of their negative charge, pectins are highly hydrated and intensely bind cations. When Ca^{2+} is added to a solution of pectin molecules, it cross-links them to produce a semi rigid gel. Such Ca^{2+} cross-links are thought to help hold cell-wall component together.

(4) Mannan: It is a homopolysaccharide of mannose and is found in the cell wall of yeast, fungi and bacteria.

(5) Agar: It is a polysaccharide, found in the cell wall of sea weeds and containing D-and L-galactose residues.

(6) Lignin: This is a biological plastic and non-fibrous material. It occurs only in mature cell walls and is made of an insoluble hydrophobic aromatic polymer of phenolic alcohols (*e.g.*, hydroxyphenyl propane).

(7) Chitin: It is a polymer of glucosamine. Glycoproteins (present up to 10 per cent in primary cell wall) are hydroxyproline- rich proteins (like the collagen). In them, many short oligosaccharide side chains are attached to hydroxyproline and serine side chains. Thus, more

than half the weight of glycoprotein is carbohydrate. These glycoproteins are known to act like the glue to increase the strength of the wall.

(8) Cutin: It is also a biological plastic and is made of fatty acids (waxes).

(9) Suberin: This is a water-resistant substance, comprising of fatty acids and found in the cork and cell wall of many plants.

(10) Sporopollenin: It is a lipoidal polymer forming tough wall (with species-specific patterns) of pollen grains.

(11) Minerals: These deposits occur in cuticle in the form of calcium and magnesium carbonates and silicates. Deposits of calcium compounds are found in the cell wall of cruciferous and cucurbitaceous plants. Silicate deposits are common in the cell wall of graminae family.

The cell wall is complex in nature and is differentiated in the following layers: (i) Primary cell wall; (ii) Secondary cell wall; (iii) Tertiary cell wall (Figure 1.2).

(i) Primary cell wall. The first formed cell wall is known as primary cell wall. It is the outermost layer of the cell and in the immature meristematic and parenchymatous cells it forms the only cell wall. The primary cell is comparatively thin and permeable. Certain epidermal cells of the leaf and the stem also possess the cutin and cutin waxes which make the primary cell wall impermeable. The primary cell wall of the yeast and the fungi is composed of the chitin.

(ii) Secondary cell wall. The primary cell wall is followed by secondary cell wall. The secondary cell wall is thick, permeable and lies near the plasma membrane of the tertiary cell wall, if the latter occurs. It is composed of three concentric layers (S1, S2 and S3) which occur one after another. Chemically the secondary cell wall is composed of compactly arranged macrofibrils of the cellulose, in between which sometimes occurs lignin as an interfibrillar material.

(iii) Tertiary cell wall. In certain plant cells, there occurs another cell wall beneath the secondary cell wall which is known as tertiary cell wall. The tertiary cell wall differs from the primary and secondary cell wall in its morphology, chemistry and staining properties. Besides the cellulose, the tertiary cell wall consists of another chemical substance known as the xylan.

Middle lamella: The cells of plant tissues generally remain cemented together by an intercellular matrix known as the middle lamella. The middle lamella is mainly composed of the pectin, lignin and some proteins.

Plasmodesmata: Every living cell in a higher plant is connected to its living neighbours by fine cytoplasmic channels, each of which is called a plasmodesma (Gr., *desmos* = ribbon, ligament; plural, plasmodesmata) which pass through the intervening cell walls. The plasma membrane of one cell is continuous with that of its neighbour at each plasmodesma. A plasmodesma is a roughly cylindrical, membrane-lined channel with a diameter of 20 to 40 nm. Running from cell to cell through the centre of most plasmodesmata is a narrower cylindrical structure, the desmotubule, which remains, continuous with elements of the SER membranes of each of the connected cells. Between the outside of the desmotubule and the inner face of the cylindrical plasma membrane is an annulus of cytosol, which often appears to be constricted at each end of the plasmodemata. These constrictions may regulate the flux

of molecules through the annulus that joins the two cytosols. Plasmodesmata are formed around the elements of smooth endoplasmic reticulum that become trapped during cytokinesis (of mitotic cell division) within the new cell wall that will bisect the parental cell. Plasmodesmata function in intercellular communication, *i.e.*, they allow molecules to pass directly from cell to cell. For example, plasmodesmata are especially common and abundant in the walls of columns of cells that lead toward sites of intense secretion, such as in nectar-secreting glands (trichomes of *Abutilon* nectaries). In such cells there may be 15 or more plasmodesmata per square micrometer of wall surface, whereas there is often less than 1 per square micrometer in other cell wall.

Lignification: The structure of cell wall is stabilized by the deposition of lignin in the cell wall matrix. Such a process of lignification was required in connection with the transition from aquatic to the terrestrial plant life during organic evolution of plants. A lignified cell wall is composed of microfibrils of cellulose embedded in the matrix containing large amount of lignin. Usually the primary cell wall becomes more lignified than secondary cell wall.

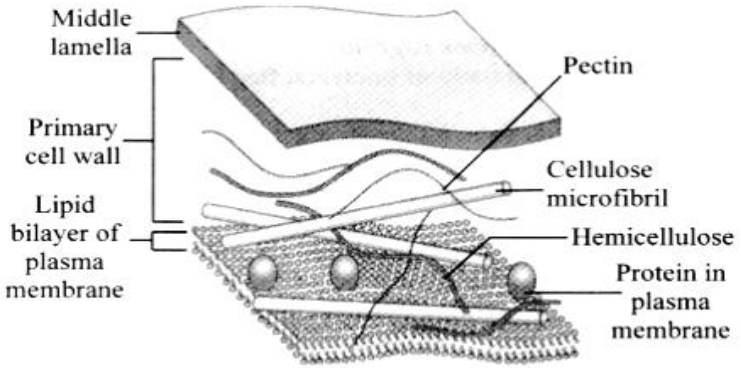


Figure-1.2: Structure of plant cell wall (https://tinyurl.com/364ur4we)

1.3.2 Functions of Cell Wall

The plant cell wall is a rigid, protective, and supportive structure surrounding plant cells. It is primarily composed of cellulose, hemicellulose, pectin, and proteins, and it plays essential roles in plant growth, defense, and communication. Here are its detailed functions:

1. Structural support and Mechanical strength: Provides rigidity and shape to the plant cell, preventing it from collapsing. Supports the overall mechanical stability of the plant, allowing it to grow upright. Strengthens tissues such as wood (which contains lignin) to support large plants and trees.

2. Regulation of cell expansion and Growth: Controls the rate and direction of cell expansion, allowing controlled growth. The primary cell wall is flexible, accommodating growth, while the secondary cell wall (in mature cells) reinforces strength. Loosening and remodeling of cell wall components allow the cell to expand in specific directions.

3. Protection against pathogens and Environmental stress: Acts as a physical barrier against bacteria, fungi, viruses, and herbivores. Contains antimicrobial compounds (e.g., phytoalexins) that prevent infections. Protects against mechanical damage, UV radiation, and dehydration.

4. Prevention of excessive water uptake (Osmotic Regulation): Prevents cell bursting due to excessive water intake by exerting turgor pressure. Maintains osmotic balance by resisting excessive expansion. Works with the vacuole to regulate water pressure inside the cell.

5. Facilitation of Cell-to-Cell communication: Contains plasmodesmata, microscopic channels that connect adjacent plant cells. Allows for exchange of nutrients, hormones, and signaling molecules between cells. Supports coordinated plant responses to environmental signals.

6. Molecular filtering and Selective permeability: Acts as a selective barrier, permitting or restricting movement of molecules. The cell wall matrix filters out harmful substances while allowing beneficial compounds to pass.

7. Wound healing and Regeneration: When plant cells are damaged, the cell wall repairs itself by producing additional wall material. Wounded areas may become reinforced with callose and lignin to seal off infections.

8. Storage of biochemicals and metabolites: Some components of the cell wall, like pectins and hemicellulose, store nutrients and energy. Acts as a reservoir of signaling molecules that regulate plant responses.

9. Facilitating Plant Cell Differentiation: Determines the shape and function of plant cells by varying its composition and thickness. Specialized cells (e.g., xylem) develop lignified secondary walls for water conduction.

10. Role in Photosynthesis and Gas Exchange: In leaf epidermal cells, the cell wall allows gas exchange while preventing excessive water loss. Some plant cell walls contain specialized structures like stomata, which regulate CO_2 and O_2 exchange.

1.4 PLASMA MEMBRANE

1.4.1 Ultra Structure

The plasma membrane is also called cytoplasmic membrane, cell membrane, or plasmalemma. The term cell membrane was coined by C. Nageli and C. Cramer in 1855 and the term plasmalemma has been given by J. Q. Plowe in 1931.

Chemical Composition

Chemically, plasma membrane found to contain proteins, lipids and carbohydrates. The details are given here under.

1. Lipids: Four major classes of lipids are commonly present in the plasma membrane i.e. phospholipids, sphingolipids, glycolipids and sterols. The relative proportions of these lipids vary in different membranes. Phospholipids may be acidic phospholipids E.g.: sphingomyelin or neutral phospholipids (phosphatidyl choline, phosphatidylserine, etc).

2. Proteins: Plasma membrane contains about 50 per cent protein. According to their position in the plasma membrane, the proteins are of two main types integral or intrinsic proteins and peripheral or extrinsic proteins, both of which may be either ectoproteins or endoproteins. The intrinsic proteins tend to associate firmly with the membrane, while the extrinsic proteins have a weaker association and are bound to lipids of membrane by electrostatic interaction. On the basis of their functions, proteins of plasma membrane can also be classified into three main types structural proteins, enzymes and transport proteins

(permeases or carriers). Some of them may act as antigens, receptor molecules (e.g., insulin binding sites of liver plasma membrane), regulatory molecules and so on. Structural proteins are extremely lipophilic and form the main bulk (i.e., backbone) of the plasma membrane.

3. Carbohydrates: Carbohydrates are present only in the plasma membrane. They are present as short, unbranched or branched chains of sugars (oligosaccharides) attached either to exterior ectoproteins or to the polar ends of phospholipids at the external surface of the plasma membrane. No carbohydrate is located at the cytoplasmic or inner surface of the plasma membrane. All types of oligosaccharides of the plasma membrane are formed by various combinations of six principal sugars i.e. D-galactose, D-mannose, L-fucose, Nacetylneuraminic acid, N-acetyl-D-glucosamine and N-acetyl-D-galactosamine.

The Fluid Mosaic Model is the most widely accepted model describing the structure of the plasma membrane. It was proposed by Singer and Nicolson in 1972 and explains how the membrane is flexible and composed of various molecules that move dynamically (Figure 1.3).

Key Features of the Fluid Mosaic Model

1. **Fluid Nature:** The phospholipid bilayer behaves like a fluid, allowing lipids and proteins to move laterally. This flexibility helps the cell membrane adapt to different conditions.
2. **Mosaic Arrangement:** The membrane is a mosaic of proteins, lipids, and carbohydrates arranged asymmetrically. These molecules are not fixed but move freely within the bilayer.
3. **Phospholipid Bilayer:** Composed of phospholipids, which have a hydrophilic head (attracted to water) and hydrophobic tails (repelled by water). Forms a bilayer where the tails face inward and the heads face outward.
4. **Proteins in the Membrane: Integral proteins**: Embedded within the bilayer, some spanning across it (transmembrane proteins). Peripheral proteins: Loosely attached to the inner or outer surface. Functions: Transport, signaling, enzymatic activity, and cell communication.
5. **Cholesterol (in animal cells):** Helps maintain membrane fluidity and stability, preventing it from becoming too rigid or too fluid.
6. **Carbohydrates (Glycoproteins and Glycolipids):** Involved in cell recognition, signaling, and immune response.

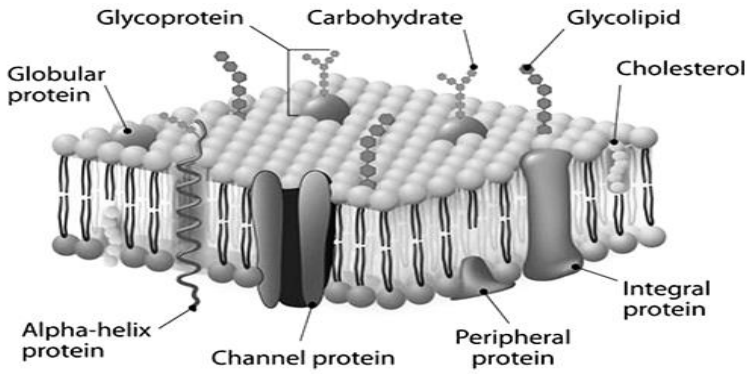


Figure-1.3: Structure of Plasma membrane (https://tinyurl.com/54mat3rj)

1.4.2 FUNCTIONS OF PLASMA MEMBRANE

The plasma membrane acts as a thin barrier which separates the intra-cellular fluid or the cytoplasm from the extra-cellular fluid in which the cell lives. Though the plasma membrane is a limiting barrier around the cell but it performs various important physiological functions.

Functions of the Plasma Membrane

1. **Selective permeability (Regulation of transport):** Controls what enters and exits the cell. Allows essential nutrients (e.g., glucose, amino acids) to enter and waste products to exit. Uses passive transport (diffusion, osmosis) and active transport (using ATP and transport proteins).
2. **Cell communication and Signal transduction:** Receptor proteins detect and transmit signals from the environment. Allows cells to respond to hormones, neurotransmitters, and other signaling molecules. Helps in coordinating cellular activities.
3. **Structural support and Cell shape**: Maintains the cell's shape and provides mechanical support. Connects to the cytoskeleton inside the cell. Helps cells attach to each other and form tissues.
4. **Cell recognition and Immune response:** Glycoproteins and glycolipids on the membrane act as cell markers. Helps the immune system distinguish self from non-self cells (prevents autoimmune attacks). Important in organ transplant compatibility and blood type recognition.
5. **Endocytosis and Exocytosis (Bulk Transport):** Endocytosis: Engulfs large molecules or particles into the cell (e.g., phagocytosis, pinocytosis). Exocytosis: Removes waste or secretes substances like hormones and enzymes.
6. **Maintaining homeostasis:** Regulates the internal environment by balancing ion concentration, pH, and water levels. Prevents excessive loss or uptake of water (especially in osmosis).
7. **Intercellular connection and adhesion:** Helps cells adhere to each other in tissues. Forms tight junctions, gap junctions, and desmosomes for communication and support.

1.5 SUMMARY

Cells are the basic units of life, with structures that support their function. The cell membrane surrounds and protects the cell, controlling the movement of substances in and out. Inside, the cytoplasm contains organelles such as the nucleus, which houses genetic material (DNA) and controls activities. The mitochondria generate energy, while the endoplasmic reticulum and Golgi apparatus help with protein and lipid processing. Ribosomes synthesize proteins, and lysosomes aid in digestion and waste removal. Plant cells also have a rigid cell wall, chloroplasts for photosynthesis, and a large central vacuole for storage. Together, these structures enable cells to grow, reproduce, and function efficiently. The plant cell wall is a rigid, protective layer surrounding the cell membrane, providing structural support, shape, and defense against pathogens. It is primarily composed of cellulose, hemicellulose, and pectin, forming a complex matrix that allows flexibility while maintaining strength. The wall is divided into the primary wall, which is thin and flexible in growing cells, and the secondary wall, which is thicker and more rigid in mature cells. Plasmodesmata, small

channels in the wall, facilitate communication and transport between adjacent cells. The cell wall also plays a crucial role in water regulation, mechanical support, and plant growth.

The plasma membrane, also known as the cell membrane, is a selectively permeable barrier that surrounds the cell, regulating the movement of substances in and out. It is primarily composed of a phospholipid bilayer with embedded proteins, cholesterol, and carbohydrates, which contribute to its fluidity and functionality. The membrane plays a crucial role in cell communication, transport, and maintaining homeostasis. It utilizes passive and active transport mechanisms, including diffusion, osmosis, and protein-mediated transport, to control the exchange of nutrients, ions, and waste products. Additionally, it facilitates cell signaling and interaction with the external environment, making it essential for cellular function and survival.

1.6 TECHNICAL TERMS

Cell organelles, Glycoproteins, Phopsholipids, Cell wall, Cellulose.

1.7 SELF ASSESSMENT QUESTIONS

Q.1 Describe the ultra-structure of eukaryotic cell.

Q.2 Describe the 'Fluid mosaic model' of the plasma membrane. On the basis of this model explain different functions of the plasma membrane.

Q.3 What is cell wall? Describe the chemical composition, structure, origin and function of the plant cell wall.

Q.4 Explain the chemical compositions of cell wall and plasma membrane.

Q.5 Brief the functions of cell wall and plasma membrane.

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Prof. V. Umamaheswara Rao

LESSON - 2

NUCLEUS, MITOCHONDRIA AND CHLOROPLAST OF EUKARYOTIC CELL

OBJECTIVE OF THE LESSON

Students are able to understand the role of nucleus in cell growth and development. Students will also know the significance of chloroplast and mitochondria in synthesis of food energy and release of energy for the metabolic activities, respectively.

STRUCTURE OF THE LESSON

2.1 INTRODUCTION

Nucleus is a membrane bound organelle found in eukaryotic cells that contains the cells hereditary information and controls the cells growth and reproduction. The nucleus is the controlling center of eukaryotic cell. It is the place where almost all the cell's DNA is confined, replicated and transcribed. Robert brown in 1831 named and discovered nucleus in plant cells. Nucleus is separated from the rest of the cytoplasm by a nuclear membrane. The location of the nucleus in a cell is usually the characteristic of the cell type and is often variable. Usually it is found in the centre of the cell. But its position may change according to

the metabolic states of the cell. Eg: Nucleus at center (embryonic cells), Nucleus at basal portion (glandular cells).

Mitochondria are essential organelles found in nearly all eukaryotic cells, often referred to as the "powerhouses" of the cell due to their role in energy production. The mitochondria (Gr., *mito*=thread, *chondrion* =granule) are filamentous or granular cytoplasmic organelles of all aerobic cells of higher animals, plants and some microorganisms including Algae, Protozoa and Fungi. These are absent in bacterial cells. The mitochondria have lipoprotein framework which contains many enzymes and coenzymes required for energy metabolism. They also contain a specific DNA for the cytoplasmic inheritance and ribosomes for the protein synthesis.

Chloroplasts were described earlier by Nehemiah Grew and Antonie van Leeuwenhoek. The term plastid was given by Schimper (1885). In 1918, Wilstatter and Stoll isolated and characterized the green pigments–chlorophylls *a* and *b*. K. Porter and S. Granick (1947) described the ultrastructure of grana of chloroplasts. The studies of Julius Sachs showed that sunlight caused chloroplasts to absorb carbon dioxide in the presence of light. Dutrochet (1837) recognized that chlorophyll was essential to oxygen evolution by plants. In 1932, Emerson and Arnold carried out the flashing light experiment and showed the existence of light and dark reactions. They introduced the concept of photosynthetic unit (PS I).

2.2 CELL NUCLEUS

Morphology

Usually, the cells contain single nucleus but the number of the nucleus may vary from cell to cell. According to the number of the nuclei following types of cells have been recognized.

I. Anucleated cells: This type of cells contain no nucleus and are, therefore, incapable of dividing to produce daughter cells. E.g.: mammalian red blood cell and sieve tubes of plants. Anucleated cell can also arise from flawed cell division in which one daughter lacks a nucleus and the other has two nuclei.

II. Mononucleate cells: Most of the plant and animal cells contain single nucleus. Such cells are known as mononucleate cells.

III. Binucleate cells: The cells, which contain two nuclei, are known as binucleate cells. E.g. some protozoans (paramecium), cartilage and liver cells, Giardia (intestinal parasite) and dinoflagelates.

IV. Multinucleate/polynucleate cells: The cells, which contain multiple nuclei ranging from 3 to 100 nuclei, are known as polynucleate cells. The polynucleate cells of the animals are termed as syncytial cells (osteoblasts, polykaryocytes of bone marrow, striated muscle cells), while the polynucleate cells of the plants are known as coenocytes (Acantharean species of protozoa, some fungi in mycorrhizae and the siphonal algae *Vaucheria* contains hundreds of nuclei).

2.2.1 Structure

The structure of a cell nucleus consists of a) Nuclear membrane/Nuclear envelope b) Nucleoplasm c) Nucleolus and d) Chromosomes.

a) Nuclear membrane: The existence of a nuclear membrane was first demonstrated by O. Hertwig in 1893. Ultra structure of nuclear envelope, pore complexes and nuclear lamina were first reported by Kirschner and his associates in 1977 as well as Schatten and Thoman in 1978. One of the main differences between prokaryotes and eukaryotes resides in the absence or presence of the nuclear envelope. The nuclear envelope or nuclear membrane consists of two cellular membranes, an inner and an outer membrane, arranged parallel to one another about 5-10 nm each and is separated by 10-50 nm space called perinuclear space (Figure 2.1). The nuclear envelope completely encloses the nucleus and separates the cell's genetic material from the surrounding cytoplasm, serving as a barrier to prevent macromolecules from diffusing freely between the nucleoplasm and the cytoplasm. The outer nuclear membrane is continuous with the membrane of the rough endoplasmic reticulum (RER), and is similarly studded with ribosomes. The perinuclear space is continuous with the RER lumen. The inner nuclear membrane, which is lined by nuclear lamina, is composed mostly of lamin proteins (polypepetides) meshwork, which is 50 to 80 nm thick or 10 to 20 nm thick. Like all proteins, lamins are synthesized in the cytoplasm and later transported into the nucleus interior, where they are assembled before being incorporated into the existing network of nuclear lamina. It lines the inner surface of the nuclear membrane, except the areas of nucleopores, and consists of a square lattice of intermediate filaments. In mammals, these intermediate filaments are of three types i.e. lamins A, B and C having their molecular weight 74,000, 72,000 and 62,000 daltons respectively.

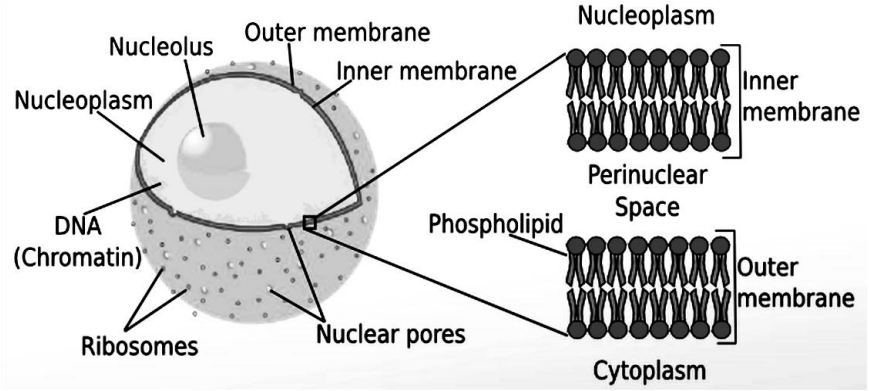

Figure-2.1: Intenral structure of nuclear membrane (https://tinyurl.com/54743fhx)

Nuclear pore complex: The materials exchanged between nucleus and cytoplasm must traverse the nuclear pore complexes. This exchange is very selective and allows passage of only certain molecules, of either low or very high molecular weight. The nuclear envelope in all eukaryotic forms, from yeasts to humans, is perforated by nuclear pores. In 1950, Callan and Tomlin observed the nucleo-pores in the nuclei of amphibian oocytes. The pores are octagonal orifices and 60 nm in diameter while, freely diffusible size is only about 9 nm wide, due to the presence of regulatory systems within the center of the pore. This size allows the free passage of small water-soluble molecules and preventing larger molecules, such as nucleic acids and larger proteins, from incorrectly entering or exiting the nucleus (Figure 2.2). Each pore complex has an estimated molecular weight of 50-100 million daltons. Particles (P) are anchored to cytoplasmic ring and are thought to be inactive ribosomes. This hole often appears to be plugged by a large central granule or plug which consist of newly made ribosomes. The pore complex perforates the nuclear envelope bringing the lipid bilayers of the inner and outer nuclear membrane together around the margins of each pore.

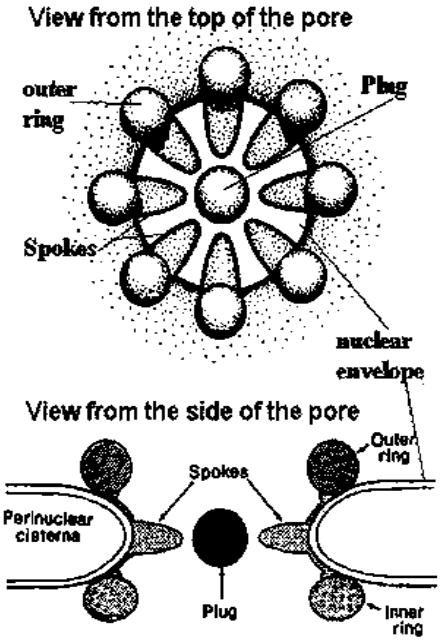

Figure-2.2: Structure of nuclear pore complex (https://tinyurl.com/msvdxdar)

Functions of Nuclear Membrane: 1. Protection of DNA **2**. Nucleo-cytoplasmic material exchange **3**. Attachment of structural elements in the cytoplasm **4**. Attachment of nuclear component during interphase **5**. Contribution to formation of other cell membranes **6**. Protein synthesis **7**. Antibody production **8**. Synthesis of chromosomal enzymes.

b) Nucleoplasm: The space between the nuclear envelope and the nucleolus is filled by a transparent, semi-solid, granular and slightly acidophilic ground substance or the matrix known as the nuclear sap or nucleoplasm. The nuclear components such as the chromatin threads and the nucleolus remain suspended in the nucleoplasm. It is composed of mainly the nucleoproteins but it also contains other inorganic and organic substances, *viz.*, nucleic acids, proteins, enzymes and minerals.

Nucleic acids: The most common nucleic acids of the nucleoplasm are the DNA and RNA. Both may occur in the macromolecular state or in the form of their monomer nucleotides.

Proteins: The nucleoplasm contains many types of complex proteins. The nucleoproteins can be categorized into following two types:

(i) Basic proteins: The proteins, which take basic stain (Feulgen – Robert Feulgen - 1924, Acridine orange- Benda - 1889) are known as the basic proteins. The most important basic proteins of the nucleus are nucleoprotamines and the nucleohistones. The nucleoprotamines are simple and basic proteins having very low molecular weight (about 4000 daltons). The most abundant amino acid of these proteins is arginine (pH 10 to 11). The protamines usually remain bounded with the DNA molecules by the salt linkage. The nucleohistones have high molecular weight, e.g., 10,000 to 18,000 daltons. The histones are composed of basic amino acids such as arginine, lysine and histidine. The histone proteins remain associated with the DNA by the ionic bonds and they occur in the nuclei of most organisms. According to the composition of the amino acids following types of histone proteins have been recognised, *e.g., histones* rich in lysine, histones with arginine and histones with poor amount of the lysine.

(ii) Non-histone or acidic proteins: The acidic proteins either occur in the nucleoplasm or in the chromatin. The most abundant acidic proteins of the euchromatin (a type ofchromatin) are the phosphoproteins.

(iii) Enzymes: The nucleoplasm contains many enzymes which are necessary for the synthesis of the DNA and RNA. Most of the nuclear enzymes are composed of non-histone (acidic) proteins. The most important nuclear enzymes are the DNA polymerase, RNA polymerase, NAD synthetase, nucleoside triphosphatase, adenosine diaminase, nucleoside phosphorylase, guanase, aldolase, enolase, 3-phosphoglyceraldehyde dehydrogenase and pyruvate kinase. The nucleoplasm also contains certain cofactors and coenzymes such as ATP and acetyl Co-A.

Lipids: According to Stoneburg (1937) and Dounce (1955), the nucleoplasm contains small lipid content.

Minerals: The nucleoplasm also contains several inorganic compounds such as phosphorus, potassium, sodium, calcium and magnesium.

Sub-Nuclear structures

Apart from these, the nucleoplasm also contains various sub-nuclear structures such as nuclear bodies, nuclear speckles, cajal bodies and promyelocytic leukemia (PML) nuclear bodies (Figure 2.3).

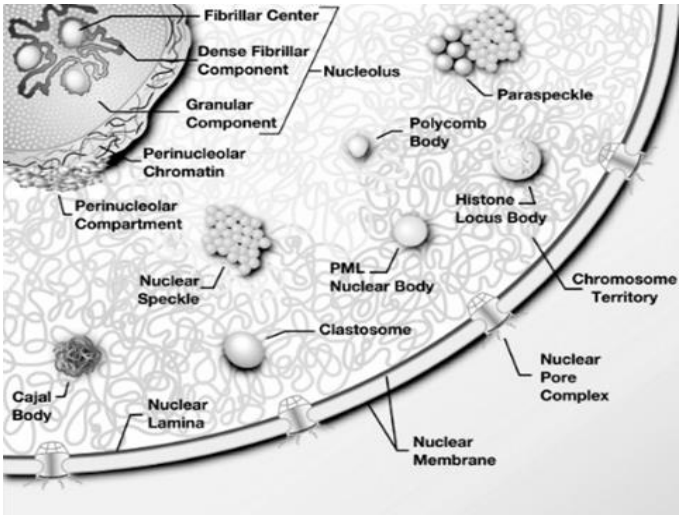

Figure-2.3: Structure of Nuclear Bodies (https://tinyurl.com/332s95dj)

Nuclear bodies: The nucleus is compartmentalized and contains numerous sub-nuclear structures called nuclear bodies. The nuclear bodies present in nucleus are nucleoli, splicing speckles, Cajal bodies (CB), gems, and promyelocytic leukemia (PML) nuclear bodies. In contrast to cytoplasmic compartments, the sub-nuclear bodies lack a membrane separating them from the nucleoplasm. These sub-nuclear bodies may serve to enhance the efficiency of specific nuclear processes.

Nuclear speckles: Nuclear Speckles, also known as interchromatin granule clusters, are irregular shaped structures of varied size and the nucleus typically contains 25-50 of these sub-nuclear bodies. Nuclear speckles are enriched in pre-mRNA splicing factors including small nuclear ribonucleoprotein particles (snRNPs) and non-snRNP protein splicing factors

eg: splicing factor SC35. Speckles are often found close to actively transcribed genes and act as a reservoir for the splicing of nascent pre-mRNA at nearby genes.

Cajal bodies: These are discovered by Santiago Ramón y Cajal (1903). Cajal bodies are roughly spherical structures numbering one to five per nucleus, varying in number and size. These structures appear in the form of coiled threads and are characterized by the presence of the coilin protein. The cajal bodies are not seen in all cells or tissues, but are especially prominent in highly proliferative cells such as cancer cells or metabolically active cells. Cajal bodies are thought to play a role in snRNP biogenesis and in the trafficking of snRNPs and small nucleolar RNPs (snoRNPs).

Promyelocytic leukemia (PML) nuclear bodies: PML bodies are characterized by the presence of PML protein. PML bodies vary in size from 0.3-1 micron meter in diameter and a nucleus typically contains 10-30 of these structures. PML nuclear bodies have emerged as important regulators of cell cycle, defense against viral infection, induction of apoptosis (tumour suppressor) and cellular senescence.

Significance of nuclear bodies: Nuclear bodies help in splicing (removal of non coding introns). Some nuclear bodies e.g. cajal bodies contains some molecules called small nuclear RNPs (sn RNPs) and small nucleolar RNPs (Sno RNPs), which helps in the splicing of some non coding sequences from mRNA and rRNA. Nuclear bodies helps in organization and formation of ribosomal subunits. Some nuclear bodies acts as transcriptional co-activator and thus enhance gene expression. Nuclear bodies such as PML nuclear bodies acts as tumor suppressor protein, provide defense against viral infection and induce apoptosis.

c) Nucleolus: Nucleolus was first observed by Fontana in the year 1781 but was described by M. J. Schleiden in 1838. The term nucleolus was coined by Bowman in 1840. It is a discrete densely stained, acidophilic body found in the nucleus. It is not surrounded by a membrane, and is sometimes called a sub-organelle. Cells of bacteria and yeast lack nucleolus. The size of the nucleolus is found to be related with the synthetic activity of the cell. Therefore, the cells with little or no synthetic activities, e.g., sperm cells, blastomeres, muscle cell, etc., are found to contain smaller or no nucleoli, while the oocytes, neurons and secretory cells which synthesize the proteins or other substances contain comparatively large-sized nucleoli. The number of the nucleoli in the nucleus depends on the species and the number of the chromosomes. The number of the nucleoli in the cells may be one, two or four. The position of the nucleolus in the nucleus is eccentric. It stains with basophilic dyes like pyronine and absorbs ultraviolet light at 260 nm.

A nucleolus is often associated with the nucleolar organizer regions (NOR) which represents the secondary constriction of the nucleolar organizing chromosomes (Figure 2.4), and are 10 in number in human beings. In 1934, Barbara Mc Clintock recognized and named nucleolar organizers in the chromosomes. It forms around tandem repeats of rDNA and DNA coding for ribosomal RNA. Nucleolar organizer consists of the genes for 18S, 5.8S and 28S rRNAs. The genes for fourth type of rRNA, i.e., 5S rRNA occur outside the nucleolar organizer. The main roles of the nucleolus are to synthesize rRNA and assemble ribosomes.

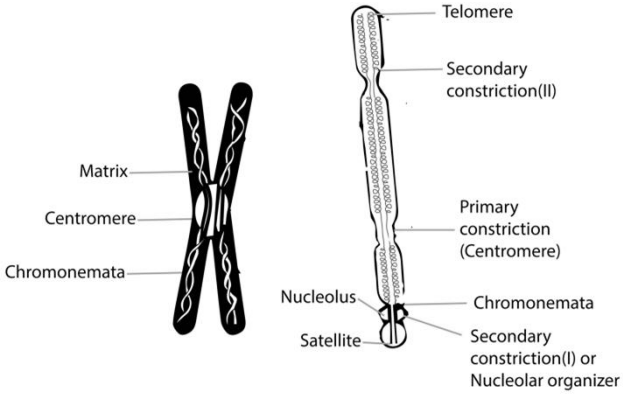

Figure-2.4: Nucleolus and nucleolus organizing region (https://tinyurl.com/9ard3ytx)

(I) Chemical composition of nucleolus: Nucleolus is not bounded by any limiting membrane; calcium ions are supposed to maintain its intact organization. Chemically, nucleolus contains DNA of nucleolar organizer, four types of rRNAs, 70 types of ribosomal proteins, RNA binding proteins (e.g., nucleolin) and RNA splicing nucleoproteins (U1, U2,.. ,U12). It also contains phospholipids, orthophosphates and Ca2+ ions. Nucleolus also contains enzymes such as acid phosphatase, nucleoside phosphorylase and NAD+ synthesizing enzymes for the synthesis of some coenzymes, nucleotides and ribosomal RNA. RNA methylase enzyme, which transfers methyl groups to the nitrogen bases, is found in the nucleolus of some cells.

(II) Ultrastructure and function of nucleolus: This nucleolus is believed to contain 3 different regions (Figure 2.5).

A. Fibrillar center: This pale-staining part represents the innermost region of nucleolus. The RNA genes of nucleolar organizer of chromosomes are located in this region. It is the place for initializing the transcription i.e., ribosomal RNA synthesis of these genes.

B. Dense fibrillar component: The dense fibrillar component surrounds the fibrillar center and RNA synthesis progresses in this region. Binding of 70s ribosomal proteins (rps) to the transcripts takes place in this region.

C. Cortical granular components: This is the outermost region of the nucleolus where processing and maturation of pre-ribosomal particles takes place.

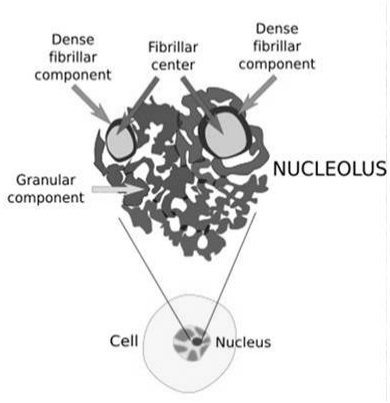

Figure-2.5: Regions of nucleolus (https://tinyurl.com/3mbhrwzf)

(III) Mitotic cycle and nucleolus: The appearance of nucleolus changes dramatically during the cell cycle. During mitosis, the nucleoli undergo cyclic changes. The nucleoli are formed around the DNA loop that extends from nucleolar organizer and disappears in prophase stage. As the cell approaches mitosis, the nucleolus first decrease in size and then disappears as the chromosomes condense and all RNA synthesis stops, so that generally there is no nucleolus in a metaphase cell. During late prophase, the DNA loop containing the rRNA genes gradually retracts and coils into the nucleolar organizer of the corresponding chromosome. Since the DNA is much extended as a consequence of intense RNA synthesis, the nucleolar organizer region is one of the last to undergo condensation, hence producing a secondary constriction on the chromosome. After the cell divides, during telophase, the nucleolar organizer DNA uncoils and the nucleolus is reassembled.

Functions of Nucleolus

1. Ribosome biogenesis: The nucleolus is primarily responsible for the production and assembly of ribosomal subunits. It synthesizes ribosomal RNA (rRNA), which is a critical component of ribosomes. The nucleolus also assembles rRNA with ribosomal proteins to form the large and small subunits of ribosomes, which are then exported to the cytoplasm for protein synthesis.

2. rRNA transcription and processing: The nucleolus contains the genes for rRNA (rDNA), which are transcribed into precursor rRNA (pre-rRNA). It processes pre-rRNA into mature rRNA through cleavage and chemical modifications.

3. Assembly of Ribosomal proteins: The nucleolus facilitates the assembly of ribosomal proteins, which are imported from the cytoplasm, with rRNA to form functional ribosomes.

4. Cell Cycle Regulation: The nucleolus plays a role in regulating the cell cycle by interacting with proteins involved in cell division and growth. It can act as a sensor for cellular stress, influencing cell cycle progression or arrest.

5. Stress response: Under stress conditions (e.g., heat shock, nutrient deprivation), the nucleolus can undergo structural changes and participate in stress response pathways. It can sequester or release specific proteins to modulate cellular responses.

6. Regulation of telomerase: The nucleolus is involved in the assembly and regulation of telomerase, an enzyme that maintains telomere length and chromosome stability.

7. Biogenesis of other Ribonucleoprotein (RNP) Particles: In addition to ribosomes, the nucleolus is involved in the assembly of other RNP particles, such as signal recognition particles (SRPs), which are essential for protein targeting to the endoplasmic reticulum.

8. Quality Control: The nucleolus ensures the proper assembly and function of ribosomes by monitoring and degrading defective rRNA or ribosomal subunits.

9. Regulation of Gene expression: The nucleolus can influence gene expression by sequestering or releasing transcription factors and other regulatory proteins.

10. Viral defense: The nucleolus plays a role in the cellular response to viral infections by interacting with viral components and participating in antiviral defense mechanisms.

d) Chromosomes or Chromatin fibers

W. Flemming (1879) coined the term chromatin for chromosomal meshwork. The cell nucleus contains the majority of the cell's genetic material in the form of multiple linear DNA molecules organized into structures called chromosomes. Each human cell contains 2 m of DNA. Most of the protein of chromatin is histone, but “non-histone” proteins are also present. The protein and DNA weight ratio averages about 1:1. Histones are constituents of the chromatin of all eukaryotes except fungi, which, therefore, resemble prokaryotes in this respect. During most of the cell cycle these are organized in a DNA-protein complex known as chromatin, but during the cell division, the chromatin can be seen to form the well-defined chromosomes. There are two types of chromatin found in the nucleus, (I) Euchromatin (II) Heterochromatin (Figure 2.6).

(I) Euchromatin: It is the less compact DNA form, and contains genes that are frequently expressed by the cell. This region can be visualized in the condensed chromosomes as the regions that stain very lightly. Euchromatin is rich in gene concentration, and is often under active transcription. Euchromatin comprises the most active portion of the genome within the cell nucleus. About 92% of the total human genome is euchromatic.

(II) Heterochromatin: It is the more compact form, and contains DNA that is infrequently transcribed. This region is stained darkly. This structure is further categorized into *facultative* heterochromatin, consisting of genes that are organized as heterochromatin only in certain cell types or at certain stages of development, and *constitutive* heterochromatin that consists of chromosome structural components such as telomeres and centromeres and is permanently condensed in all types of cells.

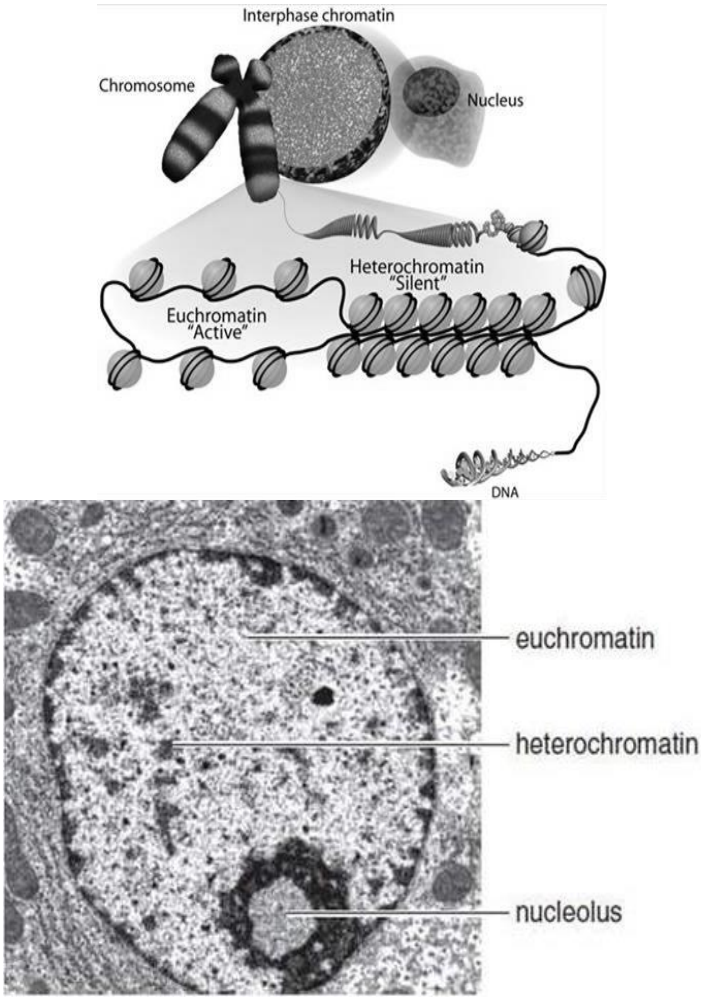

Figure-2.6: Euchromatin and heterochromatin

(https://tinyurl.com/yc5hse86 and https://tinyurl.com/4be4axwm)

2.2.2 Cell Nucleus functions

1. It controls the hereditary characteristics of an organism and is responsible for the protein synthesis, cell division, growth and differentiation.
2. Stores the hereditary material, referred to as chromatins.
3. Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
4. Nucleus is a site for transcription in which messenger RNA (mRNA) are produced for the protein synthesis.
5. Exchange of hereditary molecules (DNA and RNA) between the nucleus and rest of the cell.
6. Production of ribosomes (protein factories) in the nucleolus.
7. Selective transportation of regulatory factors and energy molecules through nuclear pores.

2.3 MITOCHONDRIA

2.3.1 Structure

The mitochondria have uniform distribution in the cytoplasm, but in many cells their distribution is very restricted. The distribution and number of mitochondria are often correlated with cell function. Typically mitochondria with many cristae are associated with mechanical and osmotic work situations e.g., muscle fibers, kidney tubule cells, and rod and cone cells of retina. Myocardial muscle cells have numerous large mitochondria called **sarcosomes**.

Number: The number of mitochondria in a cell depends on the type and functional state of the

cell. It varies from cell to cell and from species to species. e.g., the *Amoeba, Chaos chaos* (50,000), eggs of sea urchin (1,40,000), oocytes of amphibians (3,00,000). The cells of green plants contain less number of mitochondria in comparison to animal cells.

Shape and size: The mitochondria may be filamentous or granular in shape and may change from one form to another depending upon the physiological conditions of the cells. Thus, they may be of club, racket, vesicular, ring or round-shape. E.g. Granular shaped (primary spermatocyte or rat), club-shaped (liver cells) Mitochondria are remarkably mobile and constantly changing their shape. Normally mitochondria vary in size from 0.5 μm to 2.0 μm and, sometimes their length may reach up to 7 μm.

Each mitochondrion is bound by two membranes that play a crucial part in its activities. Each of the mitochondrial membrane is 6 nm in thickness and fluid mosaic in ultra structure (Figure 2.7). The outer membrane is quite smooth and has many copies of a transport protein called porin which forms large aqueous channels through the lipid bilayer. Inside and separated from the outer membrane by a 6–8 nm wide space is present the inner membrane. The inner membrane is not smooth but is impermeable and highly convoluted, forming a series of infoldings, known as cristae, in the matrix space. The inner membrane divides the mitochondrial space into two distinct chambers, 1. Peri-mitochondrial space lies between outer membrane and inner membrane. This space is continuous into the core of the crests or cristae. 2. Matrix space, which is filled with a dense, homogeneous, gel-like proteinaceous material, called mitochondrial matrix. The mitochondrial matrix contains lipids, proteins, circular DNA molecules, 55S ribosomes and certain granules. Granules are prominent in the mitochondria of cells concerned with the transport of ions and water, including kidney tubule cells, epithelial cells of the small intestine, and the osteoblasts of bone-forming cells. Further, the inner membrane has an outer cytosol or C face toward the perimitochondrial space and an inner matrix or M face toward matrix. Attached to M face of inner mitochondrial membrane repeated units of stalked particles called elementary particles, inner membrane subunits or oxysomes are present. They are also identified as F1 particles or F0-F1 particles and are meant for ATP synthesis (phosphorylation) and also for ATP oxidation.

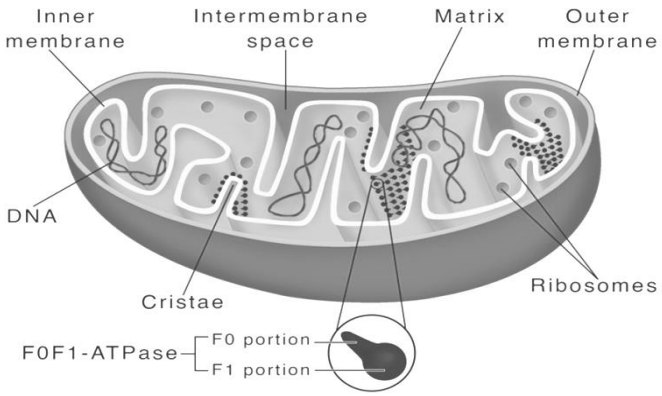

Figure-2.7: Ultra structure of Mitochondria (https://tinyurl.com/mtzhrfw7)

F1 particles: Inner membrane is studded with pin head particles called oxysomes or elementary particles or F particles or subunits of Fernandez Moran. (104 to 106 in number). Each F particle consists of three parts - Basal plate, Stalk and Head (Figure 2.8). ATP synthesis occurs in head region of oxysome because here ATPase enzyme is present. This factor also termed as Oligomycin Sensitivity Conferring Protein (OSCP). Oxysomes composed of ATPase enzymes and concerned with Oxidative phosphorylation.

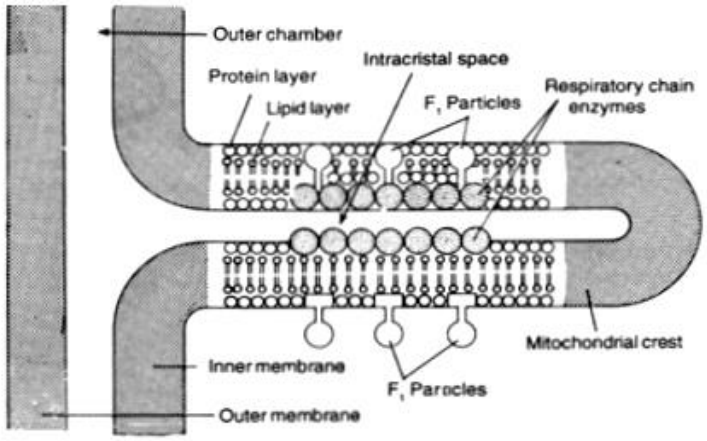

Figure-2.8: Ultra structure of F1 particle (https://tinyurl.com/56u34yz3)

Chemical Composition of Mitochondria

The gross chemical composition of the mitochondria varies in animal and plant cells. However the mitochondria are found to contain 65 to 70 per cent proteins, 25 to 30 per cent lipids, 0.5 per cent RNA and small amount of the DNA. The lipid contents of the mitochondria are composed of 90 per cent phospholipids (lecithin and cephalin), 5 per cent or less cholesterol and 5 per cent free fatty acids and triglycerides. The inner membrane is rich in phospholipid **cardiolipin** which makes this membrane impermeable to a variety of ions and small molecules e.g., Na+, K+, Cl---, NAD+, AMP, GTP, CoA etc. The outer mitochondrial membrane has typical ratio of 50 per cent proteins and 50 per cent phospholipids of 'unit membrane'. However, it contains more unsaturated fatty acids and less cholesterol. The mitochondrial regions contain a special set of proteins that mediate distinct functions.

1. Enzymes of outer membrane: Besides porins, other proteins of this membrane include enzymes involved in mitochondrial lipid synthesis and those enzymes that convert lipid substrates into forms that are subsequently metabolized in the matrix. Certain important enzymes of this membrane are monoamine oxidase, rotenone-insensitive NADH-cytochrome-C-reductase, kynurenine hydroxyalase, and fatty acid CoA ligase.

2. Enzymes of intermembrane space: This space contains several enzymes that use the ATP molecules passing out of the matrix to phosphorylate other nucleotides. The main enzymes of this part are adenylate kinase and nucleoside diphosphokinase.

3. Enzymes of inner membrane: This membrane contains proteins with three types of functions: 1. those that carry out the oxidation reactions of the respiratory chain; 2. an enzyme complex, called ATP synthetase that makes ATP in matrix ; and 3. specific transport proteins (see Table 10-1) that regulate the passage of metabolites into and out of the matrix. Since an electrochemical gradient, that drives ATP synthetase, is established across this membrane by the respiratory chain, it is important that the membrane be impermeable to small ions. The significant enzymes of inner membrane are enzymes of electron transport pathways, *viz.*, nicotinamide adenine dinucleotide (NAD), flavin adenine dinucleotide (FAD), diphosphopyridine nucleotide (DPN) dehydrogenase, four cytochromes (Cyt. b, Cyt. c, Cyt.c1, Cyt. a and Cyt. a3), ubiquinone or coenzyme Q10, non-heme copper and iron, ATP synthetase, succinate dehydrogenase; β-hydroxybutyrate dehydrogenase; carnitive fatty acid acyl transferase.

4. Enzymes of mitochondrial matrix. The mitochondrial matrix contains a highly concentrated mixture of hundreds of enzymes i.e. malate dehydrogenase, isocitrate dehydrogenase, fumarase, aconitase, citrate synthetase, α-keto acid dehydrogenase, β-oxidation enzymes. These enzymes further participate in oxidation of pyruvate and fatty acids and the citric acid cycle. The matrix also contains several identical copies of the mitochondrial DNA, special 55S mitochondrial ribosomes, tRNAs and various enzymes required for the expression of mitochondrial genes.

2.3.2 Functions of Mitochondria

The major functions carried by Mitochondria are given hereunder:

1. **ATP production (Cellular Respiration):** Mitochondria generate adenosine triphosphate (ATP), the energy currency of the cell, through oxidative phosphorylation.
2. **Regulation of Cell metabolism:** They play a role in metabolic pathways like the citric acid cycle (Krebs cycle) and fatty acid oxidation.
3. **Calcium storage and Regulation:** Mitochondria help maintain calcium ion levels, which are crucial for cell signaling and muscle contraction.
4. **Apoptosis (Programmed Cell Death):** They release cytochrome c and other factors that trigger apoptosis, helping remove damaged or unnecessary cells.
5. **Heat production:** In specialized cells, mitochondria generate heat instead of ATP, a process known as non-shivering thermogenesis (important in brown fat tissue).
6. **Hormone synthesis:** They contribute to the production of steroid hormones (e.g., estrogen, testosterone) in endocrine tissues.
7. **Reactive Oxygen Species (ROS) Management:** Mitochondria produce ROS as a byproduct of respiration and help regulate oxidative stress.

8. **DNA and Protein synthesis:** Mitochondria have their own DNA (mtDNA) and ribosomes, allowing them to produce some of their own proteins independently of the cell nucleus.

2.4 CHLOROPLASTS

2.4.1 Types of Plastids

The term 'plastid' is derived from the Greek word "*plastikas*" (= formed or moulded) and was used by **A.F.W. Schimper** in 1885. **Schimper** classified the plastids into following types according to their structure, pigments and the functions.

1. Leucoplasts: The leucoplasts (Gr., *leuco* = white; *plast* = living) are the colourless plastids which are found in embryonic and germ cells. They are also found in meristematic cells and in those regions of the plant which are not receiving light. They never become green and photosynthetic. True leucoplasts do not contain thylakoids and even ribosomes (**Carde**, 1984). They store the food materials as carbohydrates, lipids and proteins and these are of following types:

(i) Amyloplasts: The amyloplasts (L., *amyl*=starch; Gr., *plast*=living) are those leucoplasts which synthesize and store the starch. The outer membrane of the amyloplst encloses the stroma and contains one to eight starch granules. Starch granules of amyloplasts are typically composed of concentric layers of starch.

(ii) Elaioplasts: The elaioplasts store the lipids (oils) and occur in seeds of monocotyledons and dicotyledons. They also include sterol-rich **sterinochloroplast**.

(iii) Proteinoplasts: The proteinoplasts are the protein storing plastids which mostly occur in seeds and contain few thylakoids.

2. Chromoplasts: The chromoplasts (Gr., *chroma*=colour; *plast*=living) are the coloured plastids containing **carotenoids** and other pigments. They impart colour (e.g., yellow, orange and red) to certain portions of plants such as flower petals (e.g., daffodils, rose), fruits (e.g., tomatoes) and some roots (e.g., carrots). Chromoplast structure is quite diverse; they may be round, ellipsoidal, or even needle-shaped, and the carotenoids that they contain may be localized in droplets or in crystalline structures. The function of chromoplasts is not clear but in many cases (e.g., flowers and fruits) the colour they produce probably plays a role in attracting insects and other animals for pollination or seed dispersal. In general, chromoplasts have a reduced chlorophyll content and are, thus, less active photosynthetically. The red colour of ripe tomatoes is the result of chromoplasts that contain the red pigment **lycopene** which is a member of carotenoid family. Chromoplasts of blue-green algae or cyanobacteria contain various pigments such as **phycoerythrin**, **phycocyanin**, **chlorophyll a** and **carotenoids**. Chromoplasts are of following two types:

(i) Phaeoplast: The phaeoplast (Gr., *phaeo*=dark or brown; *plast*=living) contains the pigment **fucoxanthin** which absorbs the light. The phaeoplasts occur in the diatoms, dinoflagellates and brown algae.

(ii) Rhodoplast: The rhodoplast (Gr., *rhode*= red; *plast*=living) contains the pigment **phaeoerythrin** which absorbs the light. The rhodoplasts occur in the red algae.

3. Chloroplasts: The chloroplast (Gr., *chlor*=green; *plast*=living) is most widely occurring chromoplast of the plants. It occurs mostly in the green algae and higher plants. The chloroplast contains the pigment chlorophyll a and chlorophyll b and DNA and RNA.

Distribution

The chloroplasts remain distributed homogeneously in the cytoplasm of plant cells. But in certain cells, the chloroplasts become concentrated around the nucleus or just beneath the plasma membrane. The chloroplasts have a definite orientation in the cell cytoplasm. Since chloroplasts are motile organelles, they show passive and active movements.

2.4.2 Structure

Shape: Higher plant chloroplasts are generally biconvex or plano-convex. However, in different plant cells, chloroplasts may have various shapes, *viz*., filamentous, saucer-shaped, spheroid, ovoid, discoid or club-shaped. They are vesicular and have a colourless centre.

Size: The size of the chloroplasts varies from species to species. The chloroplasts generally measure 2–3 µm in thickness and 5–10 µm in diameter (e.g., *Chlamydomonas*). The chloroplasts of polyploid plant cells are comparatively larger than the chloroplasts of the diploid plant cells. Generally, chloroplasts of plants grown in the shade are larger and contain more chlorophyll than those of plants grown in sunlight.

Number: The number of the chloroplasts varies from cell to cell and from species to species and is related with the physiological state of the cell, but it usually remains constant for a particular plant cell. The algae usually have a single huge chloroplast. The cells of the higher plants have 20 to 40 chloroplasts.

A chloroplast comprises the following three main components (Figure 2.9).

1. Envelope: The entire chloroplast is bounded by an **envelope** which is made of double unit membranes. Across this double membrane envelope occurs exchange of molecules between chloroplast and cytosol.

2. Stroma: The matrix or stroma fills most of the volume of the chloroplasts and is a kind of gel-fluid phase that surrounds the grana thylakoids. It contains about 50 per cent of the proteins of the chloroplast, ribosomes and DNA molecules. The stroma is the place where CO_2 fixation occurs and where the synthesis of sugars, starch, fatty acids and some proteins takes place.

3. Thylakoids: The thylakoids (thylakoid = sac-like) consists of flattened and closed vesicles arranged as a membranous network. The outer surface of the thylakoid is in contact with the stroma, and its inner surface encloses an **intrathylakoid space**. Thylakoids may be stacked like a neat pile of coins, forming **grana** or they may be unstacked **stromal thylakoids.** There may be 40 to 80 grana in the matrix of a chloroplast. The number of thylakoids per granum may vary from 1 to 50 or more.

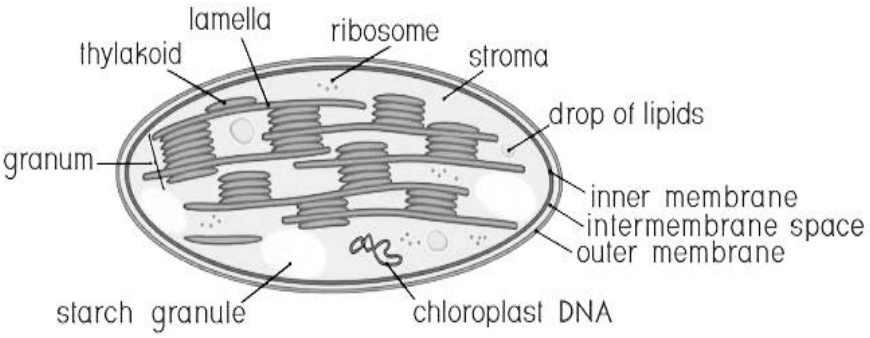

Figure-2.9: Structure of chloroplast (https://tinyurl.com/3aedt6cr)

Molecular Organization of Thylakoids

Molecular organization of the membrane of thylakoids is based on the fluid-mosaic model of the membrane which represents **fluidity**, **asymmetry** and **economy**. Lipids represent about 50 per cent of the thylakoid membrane and these directly involved in photosynthesis E.g.: **chlorophylls**, **carotenoids** and **plastoquinones**. **Structural lipids** of thylakoids include glycolipids, sulpholipids and a few phospholipids. Most of these structural lipids are highly unsaturated which confer to the fluidity of thylakoid. The protein components of thylakoid membrane are represented by 30 to 50 polypeptides which are disposed in the five major supramolecular complexes. Molecular organization of thylakoids is given in figure 2.10.

1. Photosystem I (PS I): This complex contains a reactive centre composed of P700, several polypeptides, a lower chlorophyll *a/b* ratio and β-carotene. It acts as a light trap and is present in unstacked thylakoid membranes. In it light induced reduction of $NADP^+$ takes place.

2. Photosystem II (PS II): This complex comprises two intrinsic proteins that bind to the reaction centre of chlorophyll P680. It contains a high ratio of chlorophyll *a/b* and β-carotene. Frequently, the PS IIs are associated with the light harvesting complex and are involved in light induced release of O_2 from H_2O. PS II works as a light trap in photosynthesis and is mainly present in the stacked thylakoid membranes of grana.

3. Cytochrome b/f. This complex contains one cytochrome F, two cytochromes of b 563, one FeS centre and a polypeptide. It is uniformly distributed in the grana and acts as the electron carrier. These three complexes are related to the electron transport and are linked by **mobile electron carriers** i.e., plastoquinone, plastocyanin and ferredoxin. Electron transport through PS II and PS I finally results in the reduction of the coenzyme $NADP^+$. Simultaneously, the transfer of protons from the outside to the inside of the thylakoid membrane occurs.

4. ATP synthetase: As in mitochondria, this complex consists of a **CF0** hydrophobic portion, a proteolipid that makes a proton channel, and a coupling factor one **(CF1**) that synthesizes ATP from ADP and Pi, using the proton gradient provided by the electron transport. ATP synthetase complexes are located in stacked membrane grana.

5. Light harvesting complex (LHC): The main function of LH complex is to capture solar energy. It contains two main polypeptides and both cholorophyll *a* and *b*. LH complex is mainly associated with PS II, but may also be associated with PS I. LHC is localized in stacked membranes and lacks photochemical activity.

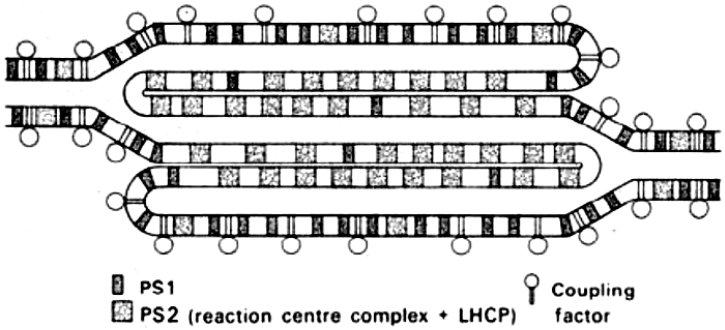

Figure-2.10: Molecular organization of thylakoids (https://tinyurl.com/3uzd2mrf)

2.4.3 Functions of the Chloroplast

Chloroplasts role in plant growth and development is very crucial and here are some the functions performed by chloroplasts.

1. Photosynthesis: Chloroplasts carry out photosynthesis, converting light energy into chemical energy in the form of glucose. This process occurs in two main stages:

Light-dependent reactions (Thylakoid Membranes): Takes place in the thylakoid membranes. Uses sunlight to excite electrons in chlorophyll. Splits water molecules (photolysis), producing oxygen (O_2) as a byproduct. Generates ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate), which are energy carriers.

Light-independent reactions / Calvin Cycle (Stroma): Takes place in the stroma. Uses ATP and NADPH to convert carbon dioxide (CO_2) into glucose through a series of enzyme-controlled reactions.

2. Production of ATP and NADPH: The chloroplast's thylakoid membranes contain ATP synthase, which produces ATP during the light reactions. NADP+ is reduced to NADPH, which is used in the Calvin cycle to fix CO_2 into carbohydrates.

3. Oxygen Production: During photolysis in the light-dependent reactions, water molecules split to release oxygen. This oxygen is essential for the survival of aerobic organisms, including plants themselves.

4. Carbon Fixation (Calvin Cycle): Uses ATP and NADPH to convert CO_2 into glucose. Involves enzyme RuBisCO (Ribulose-1,5-bisphosphate carboxylase-oxygenase), which helps fix CO_2.

5. Storage of Starch and Lipids: Excess glucose produced in photosynthesis is stored as starch in the stroma. Chloroplasts can also store lipids, which can be converted into energy when needed.

6. Synthesis of Amino Acids and Fatty Acids: Chloroplasts play a role in producing some amino acids needed for protein synthesis. They also contribute to the synthesis of fatty acids, essential for membrane formation.

7. Regulation of Plant Metabolism: Chloroplasts help regulate metabolic pathways by interacting with mitochondria and peroxisomes. They participate in photorespiration, a process where oxygen is consumed and CO_2 is released, balancing plant metabolism.

8. Defense Against Oxidative Stress: Chloroplasts contain antioxidants like carotenoids and ascorbate (vitamin C), which protect the plant cell from damage caused by reactive oxygen species (ROS).

9. Chlorophyll and Pigment Storage: Chloroplasts store chlorophyll, which captures light energy. They also contain accessory pigments like carotenoids and xanthophylls, which help absorb additional light wavelengths and protect against photo damage.

10. Intercellular Communication and Signaling: Chloroplasts communicate with the nucleus to regulate gene expression based on environmental conditions. They send signals when under stress, helping the plant adapt to changes like drought or excessive light.

11. Role in Senescence (Aging of Leaves): When leaves age, chloroplasts break down chlorophyll and transfer nutrients to other parts of the plant before the leaf falls off.

12. Adaptation to Environmental Changes: Chloroplasts can adjust their position within a cell in response to light intensity. They regulate stomatal movement by interacting with guard cells to control water loss.

2.5 SUMMARY

The cell nucleus is a membrane-bound organelle found in eukaryotic cells, serving as the control center by housing genetic material and regulating cellular activities. Nucleus is surrounded by nuclear Envelope. It is a double membrane with pores that regulate the transport of molecules between the nucleus and cytoplasm. The outer membrane connects to the endoplasmic reticulum. Nucleus contains chromatin. It is DNA wrapped around histone proteins, which condenses into chromosomes during cell division. This structure ensures efficient DNA replication and segregation. Nucleolus is a dense region where ribosomal RNA (rRNA) is synthesized and ribosome subunits are assembled. A gel-like matrix is filling the nucleus, supporting chromatin and the nuclear matrix. A filamentous network called nuclear lamina providing structural support and regulating cellular processes like DNA repair. Nucleus safeguards DNA, maintaining genetic integrity and enabling heredity through cell division. Nucleus controls gene expression by mediating transcription, thus coordinating growth, protein synthesis, and metabolism. Apart from these, nucleolus of the nucleus drives ribosome biogenesis, crucial for protein synthesis. Finally nucleus directs DNA replication and ensures accurate genetic distribution to daughter cells.

Mitochondria, the cell's energy producers, possess a highly specialized internal structure optimized for ATP synthesis through cellular respiration. It is covered by double membrane i.e Outer Membrane - Smooth and permeable due to porins, allowing small molecules and ions to pass freely. Inner Membrane - Highly folded into cristae, dramatically increasing surface area to host electron transport chain (ETC) complexes and ATP synthase. Mitochondria are rich in proteins and cardiolipin, making it impermeable to ions, crucial for maintaining the proton gradient. The compartment between the two membranes, where protons accumulate during the ETC, creating a electrochemical gradient used to drive ATP synthesis. The mitochondrial matrix contains enzymes for the Krebs cycle, fatty acid oxidation, and amino acid breakdown. It is also houses mitochondrial DNA (mtDNA), which is circular and bacterial-like, supporting the endosymbiotic theory, contains 70S ribosomes for synthesizing a subset of mitochondrial proteins. Includes nucleoids (mtDNA clusters) and granules storing ions/metabolites. Cristae maximize efficiency of oxidative phosphorylation by expanding the surface area for ETC enzymes and ATP synthase. The proton gradient across the inner membrane powers ATP synthase, converting ADP to

ATP as protons flow back into the matrix. Semi-autonomous nature due to mtDNA and ribosomes enables limited protein synthesis, though most proteins are nuclear-encoded. This compartmentalized structure ensures efficient ATP production, linking biochemical pathways (Krebs cycle, ETC) to structural features (cristae, membranes), and exemplifying form-function specialization.

Chloroplasts, the photosynthetic organelles in plants, possess a complex internal structure optimized for light-driven ATP and NADPH production. Enclosed by a double membrane, their interior comprises the stroma (a protein-rich fluid) and an extensive thylakoid membrane system. Thylakoids are flattened, membrane-bound sacs organized into stacked grana (singular: granum) interconnected by unstacked stroma lamellae, maximizing surface area for light absorption and electron transport. The thylakoid membrane is a lipid bilayer rich in galactolipids (monogalactosyldiacylglycerol, MGDG) and sulfolipids, enhancing fluidity and protein integration. It houses key photosynthetic complexes: Photosystem II (PSII) - Primarily located in grana regions, PSII contains chlorophyll and accessory pigments. It houses the oxygen-evolving complex that splits water, releasing oxygen, protons, and electrons. Cytochrome b6f Complex: Embedded in the membrane, it mediates electron transfer between PSII and PSI via plastoquinone and plastocyanin, contributing to the proton gradient across the membrane. Photosystem I (PSI) - enriched in stroma lamellae, PSI accepts electrons from plastocyanin, ultimately reducing NADP+ to NADPH. ATP Synthase - situated in stroma-exposed regions, it utilizes the proton gradient (lumen pH ~4 vs. stroma pH ~8) to synthesize ATP. The thylakoid's compartmentalization separates photochemical reactions (thylakoid membrane) from carbon fixation (stroma). The spatial segregation of complexes ensures efficient energy transfer, directional electron flow, and optimal proton gradient utilization, underpinning photosynthesis efficiency.

2.6 TECHNICAL TERMS

Nucleus, Nucleolus, Chromatin, F_1 particle, Cristae, Grana, Thylakoids, Light harvesting complexes.

2.7 SELF ASSESSMENT QUESTIONS

Q.1 Describe the structure of Nucleus and its functions.

Q.2 Write a note on Nucleolus and its functions.

Q.3 Explain how Mitochondria acts as power house of the cell and give its detailed structure and functions.

Q.4 Give a detailed structure of chloroplast and its functions with neat labeled diagram.

2.8 SUGGESTED READINGS

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2. Cell and Molecular Biology (8^{th} Edition) - De Roberties E.D.P & De Roberties (Jr.) 2017. Wolters Kluwer (India) Pvt Ltd., NewDelhi.
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Prof. V. Umamaheswara Rao

LESSON – 3

EUKARYOTIC ENDOPLASMIC RETICULUM, GOLGI APPARATUS, RIBOSOMES AND LYSOSOMES

OBJECTIVE OF THE LESSON

To understand the features and functions of endoplasmic reticulum, Golgi apparatus and ribosomes of the eukaryotic cell.

STRUCTURE OF THE LESSON

3.1 INTRODUCTION

The cytoplasm of the eukaryotic cell is coursed with a multitude of internal membranous systems and different organelles. Some of the important components of the cell are endoplasmic reticulum, Golgi apparatus, ribosomes and lysosomes. These structures perform specific functions in the cell. An extensive network of membrane limited channels occurs in cytoplasm of most of the animal cells which is referred as endoplasmic reticulum. Two types of endoplasmic reticulum viz., rough endoplasmic reticulum performs protein synthesis and smooth endoplasmic

reticulum is tasked with lipid synthesis. The Golgi apparatus, a cup shaped organelle involves in the secretion and transportation of secreted products. Whereas the degradation of several macromolecules occurs in lysosomes, the tiny spheroid or irregular shaped membrane bound vesicles.

3.2 ENDOPLASMIC RETICULUM

Endoplasmic reticulum (ER) was discovered by Keith R. Porter, A. Claude and Thompson in 1945 and the term ER was coined by Porter and Kallman in 1952. The ER found in almost all animal and plant cells except in mature erythrocytes, ova and embryonic cells. It is an extensive network of membrane limited channels that occurs abundantly in metabolically active cells and in simple form in storage cells. In spermatocytes, it is present in much reduced form. In eukaryotic cells, the ER is a part of a transportation system and has many other important functions in the cell. Some part or potion of the ER membrane remains continuous with the plasma membrane of the cell and also with the nuclear envelope. ER occupies 10% of total cell volume and its membrane accounts to 30-60% of all cellular membranes. When the cells are disrupted during fractionation, the ER breaks up into small vesicles and microsomes.

Endoplasmic reticulum membranes may assume different forms viz., cisternae, tubules and vesicles and all are filled with endoplasmic matrix. **Cisternae** are unbranched, broad, flat and membrane bound spaces arranged in parallel to each other to form into lamellae. They are interconnected with each other and present cells having active synthetic roles. **Tubules** are irregularly branched tube-like structures with a size range of 50 – 100 A^o units in diameter. These forms of tubules are very common in cells that are engaged in the synthesis of lipids and steroids. **Vesicles** or sacs appear as membrane bound and isolated globose cavities. They are round, spherical or ovoid in shape and range in size of 25 – 500 µm in diameter. They are found dispersed in cytoplasm and rich in pancreatic cells.

In eukaryotic cells, the ER exists in two morphological types namely Rough Endoplasmic Reticulum (RER) and Smooth Endoplasmic Reticulum (SER) (Figure 3.1). These two types share many of the same proteins and involve in some common activities viz., synthesis of certain lipids and cholesterol. Basing on the activities of the cell, these two types of ER occur in different ratios in different types of cells. Depending on the metabolic requirements of the cell, RER and SER are inter-convertible and RER is more stable than SER.

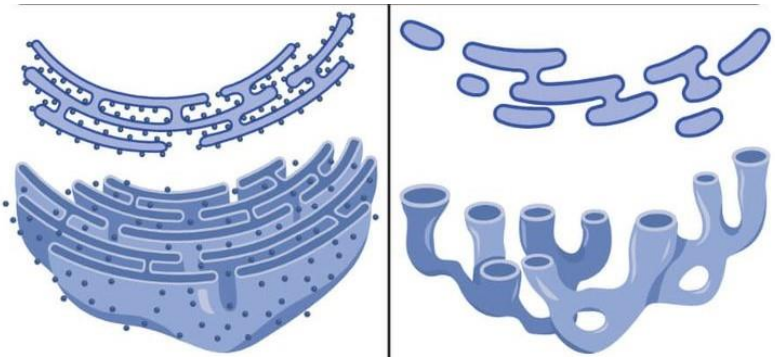

Figure-3.1:Structures of Rough endoplasmic reticulum and Smooth endoplasmic reticulum

Modifications of ER

1. **Annulate ER or Annulate lamellae:** This type of ER may be smooth or rough. They form usually from blebbing of nuclear envelope. This ER consists some pores like nuclear pores.
2. **Sarcoplasmic reticulum:** This is a modified type of SER found in striated muscle cells like skeletal and cardiac cells. It helps in intracellular impulse transmission and contraction of muscle cells. It also supplies Ca^{2+} to muscle cell cytoplasm.
3. **Myeloid body:** This is also a modified SER and mainly present in pigmented epithelial cells of frog eye retina and helps in photoreception.
4. **Nissl body:** Nissl bodies are also called as Nissl granules or tigroid body. These are the discrete granular structures present in neurons that consist of rough endoplasmic reticulum, a collection of parallel, membrane-bound cisternae and cluster of free ribosomes in nerve cells.

Some common functions of the ER includes

- Provides mechanical support to the cytoplasmic matrix.
- Provides large surface area for the synthesis of various materials.
- Helps in keeping the various cell organelles in their respective positions.
- Facilitates quick intracellular transport by forming the circulatory system in the cell.
- Controls the movement of materials between the adjacent cells by extending itself through plasmodesmata as desmotubules.

3.2.1 Rough Endoplasmic Reticulum – found mainly towards the nucleus of the cell and granular in form. It shows somewhat rough appearance due to the attachment of ribosomes on its surface. RER is predominant in cells which actively synthesize the proteins like enzyme secreting cells especially hepatocytes. RER accounts to 2/3 of the total ER content in the cell. RER is mainly composed of cisternae and tubules are few. On surface, RER contains two types of glycoproteins namely ribophorin I and ribophorin II for the purpose of attachment of ribosomes. Due to the presence of ribosomes on its surface, RER shows basophilic staining property.

Growing secretory polypeptide emerges from ribosome, it passes through the RER membrane and gets accumulated in lumen of RER. There, these polypeptide chains undergo tailoring, maturation, and molecular folding to form functional secondary or tertiary protein molecules. RER pinches off certain tiny protein-filled vesicles which ultimately get fused to cis-Golgi apparatus.

RER specific functions –

1. Helps in the formation of nuclear envelope, plasma membrane and smooth endoplasmic reticulum.
2. Holding of ribosomes by ribophores that present on RER surface.
3. Synthesizes the proteins destined for secretions, lysosomes and plasma membrane.

3.2.2 Smooth Endoplasmic Reticulum -- found towards the cell membrane or plasma membrane. SER lacks the attached ribosomes and especially abundant in mammalian liver, gonad cells and sebaceous glands. SER is agranular in nature and occurs in the form of tubules and vesicles but very rarely occurs in cisternae form. SER is characteristic of cells in which

synthesis of non-protein substances like phospholipids, glycolipids and steroid hormones takes place. It is only 1/3 of the total ER content of the cell.

SER specific functions –

1. Helps in the synthesis of phospholipids, cholesterol, steroids etc. by involving in lipid metabolism.
2. In liver cells, SER possess some enzyme bodies called glycosomes for glycogen metabolism.
3. Helps in detoxification of toxins using cytochrome P-450.
4. Provides visual pigments from Vit-A in retinal cells.
5. In muscle cells, SER modifies into sarcoplasmic reticulum which store and release Ca^{2+} for muscle contraction.
6. Involves in production of cell organelles like Golgi apparatus, lysosomes, sphaerosomes and vacuoles.

3.3 GOLGI APPARATUS

Golgi apparatus also known as Golgi body or Golgi complex was discovered in 1898 by an Italian physician Camillo Golgi for the first time in nerve cells of owl. The Golgi apparatus occurs in all cells except the prokaryotic cells and eukaryotic cells of certain fungi, sperm cells of bryophytes and pteridophytes, cells of mature sieve tubes of plants and mature sperm and red blood cells of animals. The number of Golgi bodies per plant cell may vary from several hundred (eg. corn root tissues) to a single organelle in some algal members. Largest and most complicated Golgi bodies are found in certain algal cells such as *Pinnularia* and *Microsteras*. Golgi apparatuses are more common in secretory cells and young rapidly growing cells of higher plants. In animal cells, usually a single Golgi apparatus occurs, but the number may vary from animal to animal and cell to cell types. The *Paramoeba* species shows two Golgi apparatuses, whereas the liver cells, nerve cells and chordate oocytes have many Golgi bodies.

In higher plants, Golgi bodies or dictyosomes are generally found scattered throughout the cytoplasm and not seem to be localized in any specific pattern. However, in animal cells the Golgi apparatus are polar in nature occupying a position between nucleus and periphery in case of cells of ectodermal and endodermal origin. But in nerve cells it occurs at circum-nuclear position. Morphologically, the Golgi apparatus is very similar in both animal and plant cells. However, it is pleomorphic and is compact and limited in some cell types or spread out and reticular in some other cells. The shape and form of Golgi apparatus may vary from one cell type to another cell type. However, the Golgi apparatus typically appears as a complex array of interconnecting tubules, vesicles and cisternae. The structure of the Golgi apparatus is given in Fig. 3.2.

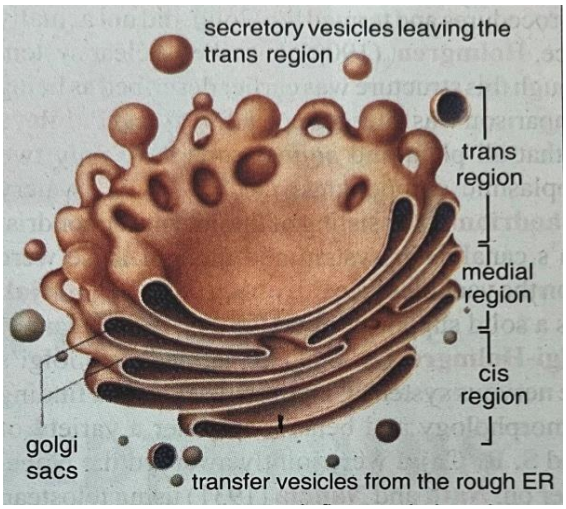

Figure-3.2: Structure of the Golgi apparatus

(Source: Cell Biology, Genetics, Molecular Biology, Evolution and Ecology – P.S. Verma and V.K.Agarwal)

Cisternae – are the elongated flattened sacs filled with fluids and piled one upon the other to form a stack like arrangement. In a stack, number of cisternae varies in general from 3 to 7 in animal cells and 20 or more in plant cells. Each cisterna is bounded by smooth unit membrane with a thickness of 7.5nm with lumen width varying from 500 nm to 1000 nm. The cisternae are slightly curved and so have convex and concave surfaces. The convex surface of the cisternae is referred to as forming face or cis-face and the concave surface is called as maturing face or trans-face. The cis-face is located towards nucleus or ER and trans-face is positioned near the plasma membrane. This type of polarization of Golgi apparatus is called as cis-trans axis. Always the new lamellae are received by cisternae from endoplasmic reticulum on the forming face and the losing membranes on the maturing face through the formation of secretory vesicles. The formation of new cisternae that results in Golgi apparatus may occur by any one of the two methods – 1. Individual stacks of cisternae may arise from the pre-existing stacks by division or fragmentation. 2. Alternatively by *de novo* formation which means the creation of something entirely new without relying on any pre-existing structure. Infact, the Golgi apparatus forms from the membranes of smooth ER which in turn originate from rough ER.

Tubules – a complex array of associated vesicles and anastomosing tubules (30 nm to 50 nm dia) surround the Golgi apparatus and radiate from it.

Vesicles – are the small droplet-like structures and closely associated with the periphery of the cisternae. They develop either by budding or by constriction of the ends of cisternae. These vesicles are of 3 types (i) **Transitional vesicles** – small, membrane limited vesicles which are assumed to form as blebs from the transitional ER to migrate and converge to cis-face of Golgi and coalesce to form new cisternae. (ii) **Secretory vesicles** – varied sized and membrane limited vesicles which discharge from cisternae margins. Often they occur between maturing face of Golgi and plasma membrane. (iii) **Clathrin-coated vesicles** – spherical protuberances with rough surface. They are morphologically quite different from secretary vesicles and usually

found at the periphery of the Golgi apparatus. These are known to perform a role in intra-cellular traffic of membranes and of secretory products i.e., between ER and Golgi.

The Golgi apparatus is surrounded by a clear and differentiated region of cytoplasm wherein ribosomes, glycogen, mitochondria and chloroplasts of absent. This region is called as zone of exclusion and the ER within this zone of exclusion has a smooth surface. The synthesized proteins appear to move in the cytoplasm in the pathway direction of – RER —› cis-Golgi—› median Golgi —› trans-Golgi —› secretory vesicles/cortical granules of egg/lysosomes.

Functions of Golgi apparatus

1. Packaging of secretory materials like enzymes, mucin, lactoprotein of milk, melanin pigment etc. that are to be discharged from the cell.
2. Processing of proteins i.e., glycosylation, phosphorylation, sulphation and selective proteolysis.
3. Synthesis of certain polysaccharides and glycolipids.
4. Sorting of proteins destined for various locations in the cell.
5. Formation of acrosome of the spermatozoa during spermatogenesis.
6. Proliferation of membranous element for plasma membrane as secretory vesicles formed from Golgi fuse with plasma membrane.
7. Biosynthesis of lysosomes as Golgi cisternae bud off small vesicles that forms into primary lysosomes.
8. Membrane trafficking – involve in intracellular and intercellular transport of the biosynthetic products.
9. Cell wall formation – during cytokinesis, Golgi vesicles accumulate in equatorial plane and helps in cell plate formation.

3.4 RIBOSOMES

Ribosomes are the remarkable organelles of the cell and they were studied before their discovery. These ribosomes were first observed in mid 1950s by George Emil Palade, Romanian-American cell biologist as dense particles or granules (Palade particles) by using electron microscope. The term ribosome was coined by Richard B. Roberts at the end of 1950s. But the first isolation was done by Tissieres and J.D. Watson in 1958 from bacterium, *Escherichia coli*. However, the detailed structure and mechanism of the ribosome was given by Venkatraman Ramakrishnan, Thomas A.Steitz and AdaE.Yonath who shared the noble prize in chemistry in 2009 for their work.

The ribosomes occur both in prokaryotic and eukaryotic cells. The presence of ribosomes in both in free state and membrane attached form was confirmed by Palade and Siekevitz through electron microscopy. Often the ribosomes occur freely in cytoplasm in prokaryotic cells. However, in eukaryotic cells, ribosomes occur freely in cytoplasm or found attached to the outer membrane surface of endoplasmic reticulum. The yeast cells, lymphocytes, meristematic plant cells, embryonic nerve cells and cancerous cells usually consists large number of ribosomes which occur freely in cytosol. In case of pancreatic cells, plasma cells, hepatic parenchymal cells, osteoblasts, thyroid cells and mammary gland cells wherein active protein synthesis takes

place, ribosomes are found attached with ER. In erythroblasts, developing muscle cells, skin and hair that synthesize specific proteins for intracellular utilization and storage may contain larger number of ribosomes and in free state.

Ribosomes in the members of eubacteria, archaea and eukaryotes of three-domain classification system resembles with each other to a remarkable degree giving an evidence for common origin. However, they differ in their size, structure, sequence, and in ratio of protein to RNA. The ribosome is a complex cellular machine and made up of with specialized RNAs namely ribosomal RNA (rRNA) and some distinct proteins whose number may vary between prokaryotic and eukaryotic cells. The ribosomal proteins and RNAs are arranged into two distinct units of different sizes, larger subunit and smaller subunit. Structurally, the ribosomes are slightly longer in axis than in diameter as are formed from two unequal size subunits. During the protein synthesis, the two subunits fit together and work as one to translate the mRNA into a polypeptide chain. There are two types of ribosomes, based on their sedimentation coefficient rate which is measured in terms of Svedberg units, namely 70S ribosomes (present in prokaryotes and in mitochondria and chloroplast of eukaryotic cells) and 80S ribosomes (occur in eukaryotic cells).

70S ribosomes – compared to 80S ribosomes, these are smaller in size with sedimentation coefficient of 70S and molecular weight of 2.7×10^6 daltons. They show a dimension of 170 x 170 x 200 A^o units. They are around 20 nm in diameter and composed of 65% rRNA and 35% ribosomal proteins. This 70S ribosome consists two subunits viz., 50S larger subunit and 30S smaller subunit. The 30S subunit consists of 16S rRNA with 1540 nucleotides that is bound with 21 proteins. These proteins associated with smaller subunit are designated as S1 to S21. The 50S subunit contains one 5S rRNA (120 nucleotides), one 23S rRNA (2900 nucleotides) and 32 to 34 proteins which are labelled as L1 to L34. In bacterial cells, several ribosomes work simultaneously on a single mRNA during protein synthesis forming a structure called as polysome or polyribosome.

80S ribosomes – in diameter these ribosomes are between 25 and 30 nm with rRNA to protein ratio is close to 1 or 50:50. In eukaryotic cells, these 80S ribosomes located in cytosol consist a smaller subunit of 40S and a larger one of 60S. The 40S subunit has 18S rRNA (1900 nucleotides) and associated with 33 proteins. The 60S larger subunit is composed of one 5S rRNA (120 nucleotides), one 28S rRNA (4700 nucleotides) and one 5.8S rRNA (160 nucleotides) with 46 proteins.

3.4.1 Molecular organization of ribosomes

The molecular organization and function of ribosomes have been studied extensively in prokaryotes than in eukaryotes. In both smaller and larger subunits, the rRNA and proteins are intertwined and arranged in a complex manner. To explain the three-dimensional structure of 70S prokaryotic ribosome, two models have been suggested – 1) Quasi-symmetrical model or Stoffler and Wittmann's model 2) Asymmetrical model or Lake's model.

Quasi-symmetrical model (Figure-3.3) – according to this, the 30S subunit has an elongated, slightly bent prolate shape and is a bipartite structure. A transverse hollow or cleft divides the 30S subunit into two parts, a smaller **head** and larger **body**. The 50S ribosomal subunit showed variations in shape basing on the different observed angles. In frontal view, 50S subunit is bilaterally symmetrical and shows three protuberances arising from a rounded base resembling

maple leaf structure wherein the central protuberance being the most prominent one. During the formation of 70S ribosome by the association of 30S and 50S subunits, the frontal face of 30S subunit with its hollow part faces the base of the 50S subunit. And the long axis of 30S subunit is oriented transversely to the central protuberance of the 50S subunit. As a result, a tunnel is formed between the hollow of the small subunit and round base of the larger subunit.

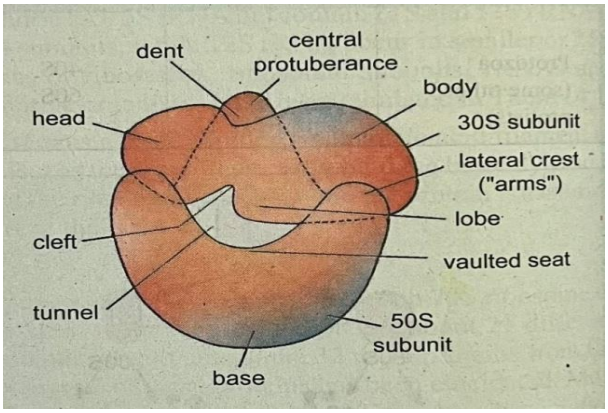

Figure-3.3: Quasi-symmetrical model of 70S ribosome

(Source: Cell Biology, Genetics, Molecular Biology, Evolution and Ecology – P.S. Verma and V.K.Agarwal)

Asymmetrical model (Figure-3.4) – this model has been suggested by James A. Lake in 1981 and is completely asymmetrical one. The smaller subunit shows a head, a base, and a platform. The head and base are separated by platform through a cleft. This cleft is considered as an important functional region and assumed to be the site of codon-anticode interaction and also as a part of binding site for initiation factors of protein synthesis. The larger subunit contains a **ridge**, a **central protuberance** and a **stalk**. The ridge and the central protuberance are separated with the help of a valley.

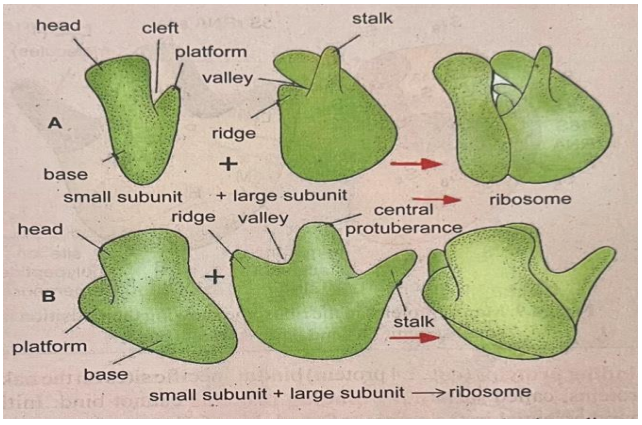

Figure-3.4: Asymmetrical model of 70S ribosome in two different orientations.

(Source: Cell Biology, Genetics, Molecular Biology, Evolution and Ecology – P.S. Verma and V.K.Agarwal)

Three-dimensional model of 80S ribosome

The cytoplasmic 80S ribosomes of eukaryotes are remarkably similar in morphology to those of prokaryotes except the differences in molecular weights, sedimentation constants, size, number of rRNAs and proteins. The 40S subunit of eukaryotic ribosome is divided into **head** and **base** segments by a transverse groove. The 60S ribosomal subunit is generally round shaped than the small unit and flattened at one side. This flat side becomes confluent with the small subunit during the formation of 80S ribosome. In addition to the cytoplasmic 80S ribosomes in eukaryotic cells, the organelles viz., mitochondria and chloroplast contains their own ribosomes but are of 70S. The ribosomes present in mitochondria are called as **mitoribosomes** and that of chloroplast are as **plastoribosomes**. Of the two, chloroplastic ribosomes are closely similar to prokaryotic ribosomes than that of mitochondrial ones.

3.4.2 Functional sites on ribosomes

Each ribosome has different functional sites viz.,

1. A-site **2**. P-site **3**. mRNA site **4**. Peptidyl transferase site **5**. EF-Tu site **6**. EF-G site **7**. 5S rRNA site and **8**. Exit site (Figure-3.5). The ribosome may be divided longitudinally into two functional domains namely Exit domain, wherein exit site is located and Translational domain that covers 2/3 of ribosome structure and contains all the remaining 7 sites.

A-site and **P-site** – these are the two distinct and adjacent sites for the attachment of aminoacyl tRNA. The tRNA first attached to A-site and then transferred to P-site, making the A-site available for the next incoming aminoacyl tRNA. Both the sites are usually located in 30S subunit.

mRNA site – is located in 30S subunit for binding of mRNA which requires protein S1.

Peptidyl transferase site – this site is localized in the central protuberance of the 50S subunit.

EF-Tu and **EF-G sites** – the EF-Tu binding site is located in the 30S subunit and close to this site in 50S subunit the EF-G binding site is located for the binding of EF-Tu and EF-G proteins.

5S rRNA site – this site is located in central protuberance of 50S subunit.

Exit site – the growing polypeptide chain is extruded through this exit site of exit domain in 50S subunit of the ribosome.

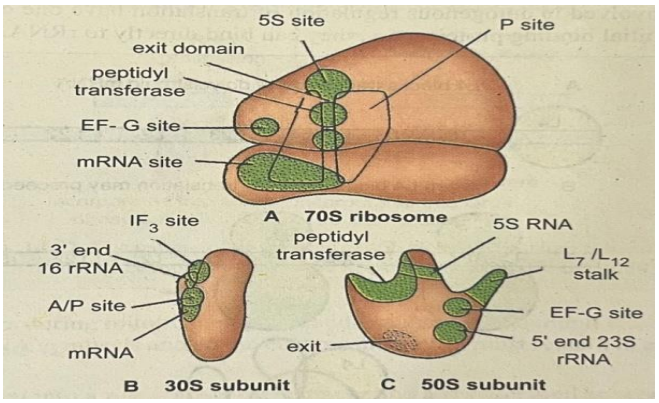

Figure-3.5: Functional sites on 70S ribosome

(Source: Cell Biology, Genetics, Molecular Biology, Evolution and Ecology – P.S. Verma and V.K.Agarwal)

Comparison of 70S and 80S ribosomes

Eukaryotic 80S ribosomes differ from that of prokaryotic 70S ribosomes in means of –

1. Larger in size.
2. Containing more number of proteins associated.
3. Having four types of rRNA molecules instead of three types.
4. Large-sized proteins and nucleic acids.
5. rRNA –protein ratio is 1:1 instead of 2:1 in 70S ribosomes.
6. Resistant to antibiotic chloramphenicol whereas 70S ribosome is susceptible. But 80S is sensitive to cycloheximide and protein synthesis is inhibited.

The prime and important function of both prokaryotic and eukaryotic ribosomes is the assembly of amino acids to form polypeptide proteins that are essential to perform various cellular functions. The proteins synthesized by free located ribosomes are usually utilized in the cytoplasm itself. But the proteins that are synthesized by bound form of ribosomes are transported to outside of the cell.

3.5 LYSOSOMES

Lysosomes are the tiny membrane-bound vesicles involves in intracellular digestion. The term lysosome is derived from Greek language *lyso*=digestive and *soma*=body. In 1955, C. de Duve discovered and named these organelles as lysosomes. For the work on lysosomes, he shared the noble prize in 1974 along with Palade and Claude in the field of physiology. They consists a variety of hydrolytic enzymes which remain active in acidic conditions. These organelles are important in digestion of a variety of biological materials and also cause aging and death of animal cells. The lysosomes occur in most of the animal cells and few plant cells but totally absent in bacteria and mature mammalian erythrocytes. Few lysosomes occur in muscle cells but rich and abundant in granulocytes, phagocytic cells, and epithelial cells of absorptive, secretory and excretory organs, lungs and uterus.

Lysosomes are the round vacuolar structures bounded with single unit membrane and filled with dense material. Lysosomes vary greatly in shape and density with a size range of 0.2 to 0.5µm.

The size and shape of lysosomes vary from cell to cell and time to time. The lysosome may consist up to 40 types of hydrolytic enzymes that include proteases, nucleases, glycosidases, lipases, phospholipases, phosphatases and sulphatases. All the lysosomal enzymes are acid hydrolases and optimally active at pH 5.0 within the organelle. The lysosomal membrane contains substantial amounts of carbohydrate material, particularly sialic acid. Most of the lysosomal membrane proteins are usually highly glycosylated and the membrane shows an unique property of fusing with other membranes of the cell. Lysosomal membrane can be destabilized and ruptured which result in the release of lysosomal enzymes by surface active agents such as liposoluble vitamins and steroid sex hormones. However, the cortisone, hydrocortisone and other drugs tend to stabilize the lysosomal membrane. The entire digestion process occurs within the lysosome and acidification of lysosomal content depends on an ATP-dependent proton pump that present in lysosomal membrane. The lysosomal membrane also contains transport proteins which allow the digested macromolecules to exit so that they can be excreted or reutilized by the cell.

3.5.1 Polymorphism in lysosomes

Lysosomes are extremely dynamic organelles and exhibit polymorphism in their morphology. Totally, four types of lysosomes have been recognized in different types of cells or at different times in the same cell. Of the four lysosomes, first one is referred as Primary lysosome and the remaining three viz., Heterophagosomes, Autophagosomes, and Residual bodies are grouped together and considered as Secondary lysosomes.

Primary lysosomes - also called as storage granules, protolysosomes or virgin lysosomes. These are the newly formed, single membrane bounded organelles with a typical diameter of 100 nm. They contain degradative enzymes which will not involve in any digestive process. Each primary lysosome contains one or another type of enzyme and only exhibit hydrolyzing activity.

Heterophagosomes – also be referred as heterophagic vacuoles, heterolysosomes or phagolysosomes. These are formed by the fusion of primary lysosomes with cytoplasmic vacuoles containing extracellular substances that are carried into the cell by a variety of endocytic processes namely pinocytosis, phagocytosis or receptor-mediated endocytosis. The engulfed substances are digested by the activity of hydrolytic enzymes present in secondary lysosomes. The digested low molecular material can readily passes through the lysosomal membrane and become the part of the cell matrix.

Autophagosomes – these are also be called as autophagic vacuoles, cytolysosomes or autolysosomes. Primary lysosomes are also able to digest the intracellular structures including mitochondria, ribosomes, peroxisomes and glycogen granules of the cell. This type of autodigestion is a normal event that occurs during cell growth and repair which may be prevalent in cells undergoing programmed cell death in the process of metamorphosis or regeneration and also in the tissues under stress. This autophagy may occur in different modes. Sometimes, the lysosome appears to move around the cell organelle and fuse with and enclose it in a double membrane sac. Then, the inner membrane breaks down and the lysosomal enzymes penetrate into the enclosed organelle. In other cases, the organelle to be digested is first fenced by smooth endoplasmic reticulum forming a vesicle which then fuses with a primary lysosome. Lysosomes can also regularly engulf small portions of cytoplasmic matrix and is degraded by a process which is referred to as microautophagy.

Residual bodies – also called as telolysosomes or dense bodies. These are formed due to the incomplete digestion in food vacuole because of the absence of some lysosomal enzymes. The residual bodies are generally large, irregular in shape and electron-dense. In some cells of A*moeba* and other protozoa, these residual bodies are eliminated by defecation process. In other cases, residual bodies may remain for longer periods in cells and result in their aging. For example, the presence of aging pigment inclusions in some nerve cells, liver cells, heart cells and muscle cells of old animals is due to the accumulation of these residual bodies.

Functions of lysosomes

1. Digestion of large extracellular particles i.e. food contents of phagosomes and pinosomes.

2. Digestion of intracellular substances – during starvation, lysosomes digest the stored food contents viz., proteins, lipids, some carbohydrates of the cell cytoplasm and supply the needed energy to the cell.

3. Autolysis – in certain pathological and disaster conditions, lysosome digest the various organelles of the cells particularly of dead ones.

4. In case of sperm cells, during fertilization, lysosomes discharge their enzymes to outside the cell and digest the limiting membranes of the ovum thereby facilitate the penetration of sperm into the ovum.

3.5.2 Lysosomes in plants

Several of the hydrolases in plant cells are not always neatly compartmentalized and not necessarily present in membrane bound vacuoles as in animal cells. Instead, many types of vacuoles and storage granules in plant cells are found to contain certain digestive enzymes and thereby these granules are considered as lysosomes of plant cell in 1972 by Gahan. Matil in 1975 has divided these structures into three types viz., Vacuoles, Spherosomes and Aleurone grain.

1. Vacuoles – the vacuole of a mature plant cell forms from the enlargement and fusion of smaller vacuoles present in meristematic cells. These provacuoles are believed to be derived from the ER and possibly the Golgi and contain acid hydrolases. Sometimes, mitochondria and plastids are observed inside the vacuoles which suggest the autophagy in plants.

2. Spherosomes – these are the membrane-bound, spherical structures with a size of 0.5 to 2.5 µm diameter and occur in most plant cells. They originate from the ER and during this process, oil accumulates at the end of a strand of ER and then a small vesicle is cut off to form particles known as prospherosomes. These prospherosomes grow in size to form spherosomes. The basic functions of spherosomes are lipid synthesis and storage. But in maize root tips and tobacco endosperm tissue, the spherosomes are found rich in hydrolytic digestive enzymes and so considered as lyosomes.

3. Aleurone grain – also called as protein bodies which are spherical membrane-bound storage particles that generally occur in cells of endosperm and cotyledons of seeds. Usually, they form during the later stages of seed ripening and disappear in the early stages of germination. They store proteins and phosphate in the form of phytin. Like spherosomes, aleurone grains store

reserve materials, mobilize them during germination and in addition form a compartment for the digestion of other cell components.

3.6 SUMMARY

The cytoplasmic matrix of a eukaryotic cell is traversed by a complex network of inter-connecting membrane bound vacuoles or cavities which often remain concentrated in the endoplasmic portion of cytoplasm and referred as endoplasmic reticulum. The rough endoplasmic reticulum that is associated with ribosomes on its surface function mainly in protein synthesis. Whereas, the smooth endoplasmic reticulum devoid of attached ribosomes involves in lipid synthesis. The Golgi apparatus carry out certain cellular functions like the biosynthesis of polysaccharides, compartmentalization of cellular synthetic products, production of exocytotic secretory vesicles and differentiation of cellular membranes. Golgi apparatus is a system of sacs, with parallely arranged, flattened, membrane bounded vesicles. The ribosomes of both 70S (prokaryotic ribosomes) and 80S (eukaryotic ribosomes) types referred to as work benches for making the proteins. A ribosome is a small dense and granular ribonucleoprotein particle which serves as the site for protein synthesis in the cell. The ribosome reads the sequence of the mRNA and, using the genetic code, translates the sequence of RNA bases into a sequence of amino acids. Lysosomes are the tiny, membrane-bound vesicles containing a variety of hydrolytic enzymes and involve in the digestion of various biological materials in the cells.

3.7 TECHNICAL TERMS

Rough endoplasmic reticulum, Smooth endoplasmic reticulum, Golgi apparatus, Cisternae, Vesicles, 70S ribosomes, 80S ribosomes, Primary lysosomes, Heterophagosomes, Autophagosomes, Vacuoles, Spherosomes, Aleurone grain.

3.8 SELF ASSESSMENT QUESTIONS

Q.1 Explain in detail about the structure and functions of endoplasmic reticulum.

Q.2 Write an account on the Golgi apparatus.

Q.3 Describe the types of ribosomes and its structure and functions.

Q.4 Give an account on lysosomes of animal and plant cells.

3.9 SUGGESTED READINGS

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Prof. V. Umamaheswara Rao

LESSON - 4

CELL CYCLE AND PHASES OF CELL CYCLE

OBJECTIVE OF THE LESSON

Students will understand the process and different phases of the cell cycle and their significance in cell division.

STRUCTURE OF THE LESSON

4.1 INTRODUCTION

Growth is defined as an increase in size or mass of a developing/living system. It is an irreversible process that takes place at all levels of the organization. It is often difficult to define since it is multifactorial, that is, growth embodies the following three interconnected growth patterns:

(1) Auxetic growth: an increase in cell mass or auxesis.

(2) Multiplicative growth: an increase in cell number due to cell division.

(3)Accretionary growth: growth due to accumulation of extracellular products.

4.2 CELL CYCLE

All cells are formed through divisions of pre-existing cells. Cell division is necessary for the continuation of life. A cell born after a division grows by macromolecular synthesis until it reaches a species-determined division size and then divides. This cycle serves as a biological time unit, defining a cell's life history. The cell cycle is defined as the full sequence of events that occur between the end of one nuclear division and beginning of the next. The cell cycle involves three modes of cycles -

1. Chromosome cycle: DNA synthesis alternates with mitosis. During DNA synthesis, each double-helical DNA molecule is duplicated into two identical daughter DNA molecules. During mitosis, the duplicated copies of the genome are eventually separated.

2. Cytoplasmic cycle: Cell proliferation alternates with cytokinesis. During cell development, several other components of the cell (RNA, proteins, and membranes) double in amount, and during cytokinesis, the cell divides in two. Normally, cytokinesis follows karyokinesis, but sometimes it does not and resulting in a multinucleate cell. E.g.Cleavage of egg in Drosophila.

3. Centrosome cycle: The centrosome must be accurately replicated and inherited in both of the aforementioned cycles in order to create the two poles of the mitotic spindle. The cell cycle's third component is the centrosome cycle.

4.3 PHASES OF CELL CYCLE

Howard and Pelc (1953) have divided cell cycle into G_1, S, G_2 and M phases (Figure 4.1). The G_1, S and G_2 phasestogether form the classical interphase.

G_1 Phase: The G_1 phase is also known as the initial growth phase or the post-mitotic gap phase. It is the most extended phase of cell division. In this phase, various types of RNA (mRNA, tRNA, and rRNA) and proteins are synthesized. In plant cells, all cell organelles multiply, including the endoplasmic reticulum, mitochondria, the Golgi complex, ribosomes, and plasmids. The duration of G_1 Phase differs from cell to cell. It is shorter in frequently dividing cells. The duration of the G_1 phase varies greatly, ranging from 30 to 50 percent of the total time of the cell cycle. G_1 phase is completely absent in rapidly proliferating cells such as blastomeres of early embryos in frogs and mammals. G_1 phase cells have three possibilities. a) Continues the cycle and enters S phase. b) Stops the cell cycle and enters quiescent or G_0 phase. c) Terminates the cell cycle and initiates cell differentiation. The availability of mitogens and energy rich substances determines the aforementioned option. This point is known as a checkpoint. The following proteins are produced during the G_1 phase: (1) regulatory proteins that regulate different aspects of mitosis; (2) enzymes (like DNA polymerase) required for DNA synthesis; and (3) tubulin and other proteins of the mitotic apparatus.

S phase: DNA replication and histone protein synthesis occur during interphase's S phase, also known as the synthetic phase. To provide nucleosomes to the newly synthesized DNA, enormous numbers of new histones are required immediately at the start of the S phase. At the end of S phase, each chromosome contains two DNA molecules and a double set of genes. S phase accounts for around 35 to 45 percent of the cell cycle.

G_2 phase: During the G_2 phase of the cell cycle, RNA and protein synthesis continues, which is necessary for cell growth. The G_2 phase may take up 10 to 20% of the cell cycle's time. As the G_2 phase ends, the cell enters the M phase, where DNA synthesis stops and RNA and protein synthesis continues. All cell organelles multiply, and spindle formation occurs. The synthesis of tubulin protein is essential for spindle formation. The synthesis of protein is essential for plasma membrane development. A large number of ATP molecules are required to transfer

chromosomes from the equator to the pole (30 ATP/chromosome). It lasts between 2 and 5 hours in most cells. Some proteins generated during this period trigger chromosomal condensation, which initiates mitosis.

G0-phase: The G_0 phase, also known as the quiescent stage, is a period in which cells do not divide further (i.e., do not enter S-phase after G_1-phase) and undergo differentiation. This is due to a lack of mitogens and energy rich compounds, and the cells remain metabolically active, grow in size, and differentiate for a specific function after achieving a specific shape. However, some cells remain undifferentiated as reserve cells, and they may divide when necessary.

Interphase

General Events of Interphase: The nuclear envelope is still intact. Chromosomes have the form of dispersed, lengthy, coiled, and barely visible chromatin fibers. The amount of DNA doubles. In animal cells, a daughter pair of centrioles develops near an existing centriole, thus an interphase cell has two pairs of centrioles. Net membrane biosynthesis in animal cells increases shortly before cell division (mitosis). This excess membrane appears to be stored as blebs on the surfaces of cells that are preparing to divide.

M phase or Mitotic phase: Somatic cells go through mitosis (Greek for "thread"). It is intended to increase the number of cells during plant and animal embryogenesis and blastogenesis. Mitosis initiates at the end of interphase (G_2 phase). It is a brief stage that includes chromosomal condensation, segregation, and cytoplasmic division. Mitosis is essential for replacing cells destroyed due to natural friction. The mitotic phase of the cell cycle is divided into four distinct phases: prophase, metaphase, anaphase, and telophase. During prophase, chromatin begins to condense and chromosomes become visible. Metaphase can be divided into two stages: prometaphase and metaphase, during which the nuclear envelope begins to break down and the chromosomes begin to align at the cell's equatorial plane. In anaphase, sister chromatids divide and migrate to opposing poles, whereas in telophase, daughter chromosomes reach opposite poles and form two daughter nuclei. This is followed by cytokinesis, which is the last stage of mitosis. During cytokinesis, the cytoplasm is divided into two halves, and the cell divides into two daughter cells.

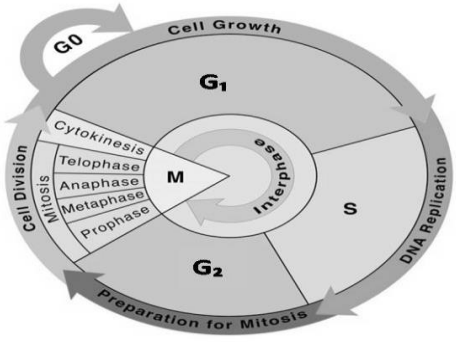

Figure-4.1: Phases of Cell cycle (https://tinyurl.com/57u2zbh9)

4.4 CHECKPOINTS OF THE CELL CYCLE

Checkpoints in the cell cycle ensure that each phase of the cell division cycle is completed correctly. The checkpoints in the cell division cycle ensure that specific conditions can be fulfilled before the cell progresses from one phase to the next. The cell division cycle has three key checkpoints: G_1, G_2, and M (Figure 4.2).

G1 Check point: The G_1 checkpoint, sometimes referred to as the G_1 checkpoint, activates when the circumstances are ideal for cell division. At this checkpoint, the cell examines its size, nutrition, DNA damage, and all the preparations such as proteins, ATP, etc. that are necessary for the S phase. The final step is to determine whether the Cdk complex and S phase cyclins are activated to start DNA replication.The cell then moves on to the subsequent S phase. The cell is now dedicated to completing the full cell cycle after passing the G_1 phase. When an unfavorable circumstance arises, the cell either tries to fix itself or moves into the G_0 phase of the cell division cycle. The cell activates the G_2 checkpoint after passing the G_1 checkpoint.

G_2 check point: This check often occurs following the S phase. The G_2 checkpoint's principal role is to monitor DNA quality and ensure appropriate DNA replication. After establishing that proper replication occurred in the S phase, the cells enter metaphase via spindle assembly. Apoptosis occurs when cells are unable to fix replication mistakes. This prevents the passing of damaged DNA to the daughter cells. The cell also checks for all preparations (e.g., all proteins, ATP, etc.) required in the M phase. Cells also check for tubulin production and whether M phase cyclins and the Cdk complex are active to commence mitosis. The cell then moves on to the next M phase.

M Check point: The third checkpoint, also known as the M checkpoint, occurs during the metaphase to anaphase transition. This checkpoint is also known as the spindle checkpoint because it ensures that all sister chromatids are appropriately linked to the spindle microtubules that separate them. The cell remains in mitosis until all sister chromatids are properly joined.

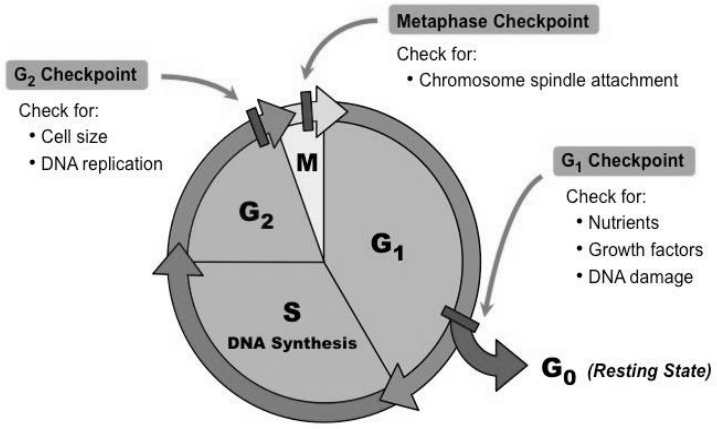

Figure-4.2: Check points of Cell cycle (https://tinyurl.com/2w92rpxs)

4.5 MOLECULAR BASIS OF CELL CYCLE REGULATION

There are controls on the cell cycle. The cell's preparations are examined by regulatory molecules. It involves identifying and fixing genetic damage and stopping unchecked cell division. The correct progression of a cell through the cell cycle is determined by two crucial types of regulatory molecules. These are 1. Cyclins 2. Kinases that are cyclin-dependent (Cdk). Leland H. Hartwell, Tim Hunt, and Sir Paul M. Nurse shared the 2001 Nobel Prize in Physiology or Medicine in recognition of their identification of important cell cycle regulators.

Cyclins

Cyclins regulate CDK activity. Cyclins are classified into four types based on their presence and activity during the cell cycle. **1**. D Cyclins **2**. Cyclin E **3**. S-phase cyclins **4**. M-phase cyclins (Figures 4.3 and 4.4).

Cyclin D: G_1 cyclins regulate the cell cycle and extracellular events. Their activity is regulated by signal transduction pathways that detect the presence of growth stimulants or cell proliferation inhibitory signals. The G_1 cyclin interacts with CDK4 and CDK6 to induce cell cycle entry.

Cyclin E: During the late G_1 phase, G_1 cyclins begin to accumulate, achieving peak levels as cells progress into the S phase, followed by a subsequent decline during S phase. Cyclin E, which binds to CDK 2, is a key player in this process. The cyclin E-CDK 2 complex, in collaboration with the cyclin D-CDK4/6 complex, primarily functions to promote the G_1-S phase transition. This transition, known as START, marks the definitive point at which cells are permanently committed to division, thus eliminating the possibility of reverting to the G_1 phase.

S phase cyclins: The synthesis of S phase cyclins occurs at the end of the G_1 phase, with their concentrations remaining elevated during the S phase and not diminishing until the early stages of mitosis. Two distinct types of S phase cyclins are responsible for triggering the S phase: cyclin E, which also aids in the cell cycle entry and is categorized as a G_1/S cyclin, and cyclin A. Both cyclins interact with CDK2 and are essential for the initiation of DNA synthesis.

Mitotic cyclins: The binding of mitotic cyclins, namely cyclin A and cyclin B, to CDK1 is essential for the transition into and the progression of mitosis. The synthesis of these cyclin-CDK complexes occurs during the S and G_2 phases, but their activation is delayed until the DNA synthesis process is complete. The various types of cyclins exhibit significant differences in their protein sequences; however, they all share a conserved region referred to as the cyclin box and display comparable three-dimensional structures.

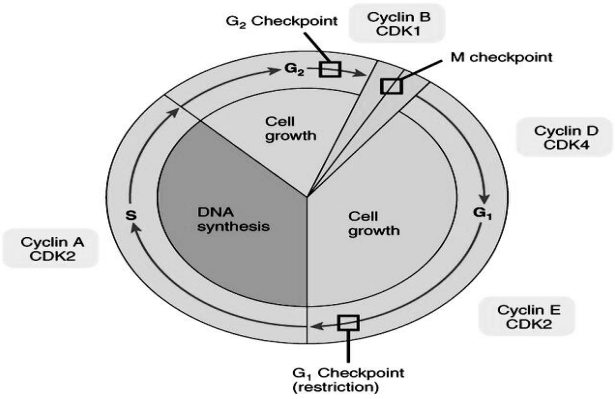

Figure-4.3: Cyclin dependent kinases (Cdk) complexes (https://tinyurl.com/a3t3tdnp)

Three key features of Cyclins:

1. Cyclins serve to bind and activate CDKs. The specific activity and substrate targeting of any CDK are mainly influenced by the specific cyclin that it is associated with.
2. The occurrence of cyclins is limited to the stages of the cell cycle that they stimulate, and they are not present in any other cell cycle stages.
3. Beyond their regulatory function at specific cell cycle stages, cyclins initiate a series of events that prepare the cell for the next phase. This action is vital for the continuous progression of the cell cycle.

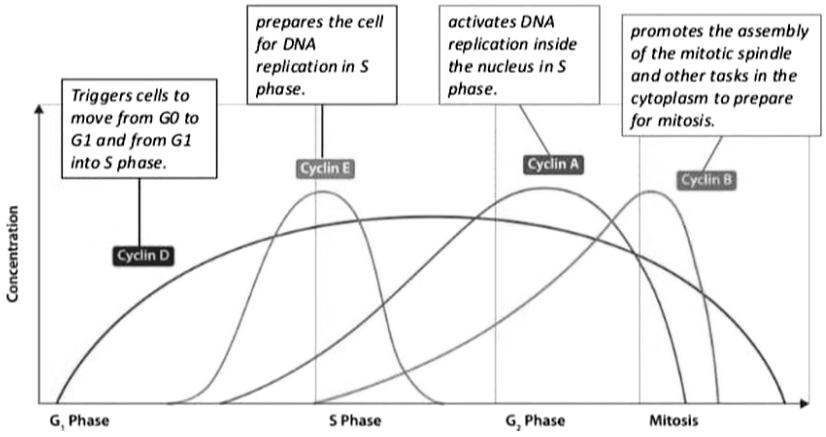

Figure-4.4: Cyclin Expression Cycle (https://tinyurl.com/edy7f5ad)

Cyclin dependent kinases (Cdks cell cycle)

Cyclin-dependent kinases (CDKs) are protein kinases characterized by needing a separate subunit a cyclin that provides domains essential for enzymatic activity. CDKs play important roles in cell cycle regulation(the control of cell division and modulate transcription in response to several extra- and intracellular cues). The evolutionary expansion of the CDK family in mammals led to the division of CDKs into three cell-cycle-related subfamilies i.e. 1. G_1 Cdk (Cdk 4) 2.S-phase Cdk (Cdk 2) 3.M-phase Cdk (Cdk 1).Their levels in the cell remain stable and remain inactive. They bind to the appropriate cyclin in order to be activated. Their function is to

provide phosphate group to a number of proteins that control processes in the cell cycle. A CDK binds a regulatory protein (cyclin). Without cyclin, CDK has little kinase activity, only the cyclin-CDK complex is an active kinase but its activity can be typically further modulated by phosphorylation and other binding proteins, like p27. Various types of Cyclin and Cdks complexes are formed during cell cycle regulation and their functions are represented in Table 4.1

Table 4.1-Cyclin - CDKs Complex

Phase of cell cycle	Cyclin	Cdk	Cyclin-Cdk complex	Function
G1	Cyclin D	Cdk 4	G1 Cyclin-G1 Cdk	Inhibits Rb protein and signals the cell to prepare the chromosome for replication
S	Cyclin E and Cyclin A	Cdk 2	S phase cyclin – S phase Cdk	Activates DNA replication
G2	Cyclin B	Cdk 1	Mitotic cyclins – M phase Cdk	Activates mitosis

4.6 MECHANISM OF CELL CYCLE REGULATION BY CDKS ACTIVATION

Multiple mechanisms ensure that CDKs are active in the right stage of the cell cycle. CDK activity is regulated by multiple mechanisms and the cells utilize multiple mechanisms to restrict cyclins to the appropriate cell cycle stage and to keep them at the right concentration.

1. Regulating of Cyclin Mechanisms
2. Action of CDK-activating kinase (CAK)
3. Inhibitory phosphorylations on CDK
4. Action of CDK Inhibitors

1. Regulation of Cyclin Mechanisms

Cyclin-dependent kinases (CDKs) operate similarly to other protein kinases by targeting the covalent bonds within phosphate groups derived from ATP, which are then transferred to protein substrates. This action leads to the disintegration of the nuclear membrane. CDKs facilitate the progression of the cell from the G_1 phase to the S phase, as well as from the G2 phase to the M phase during the cell division cycle. The fluctuating levels of cyclins are crucial for enabling the cell to transition between these phases. This phase transition is made possible through the periodic phosphorylation of specific components involved in the cell cycle. The activation of cyclin-dependent kinases (CDKs) is not possible without their association with specific regulatory proteins known as cyclins. Consequently, the variations in CDK activity during the cell cycle are mainly driven by changes in the concentration of cyclins. During each stage of the cell cycle, distinct cyclins are synthesized, leading to the formation of various cyclin-CDK complexes specific to that stage (Figure 4.5). Each of these complexes plays a crucial role in initiating specific events associated with the cell cycle. Additionally, the levels of cyclins and the

activity of CDKs are regulated by a variety of cellular mechanisms, forming a network that governs the overall regulation of the cell cycle.

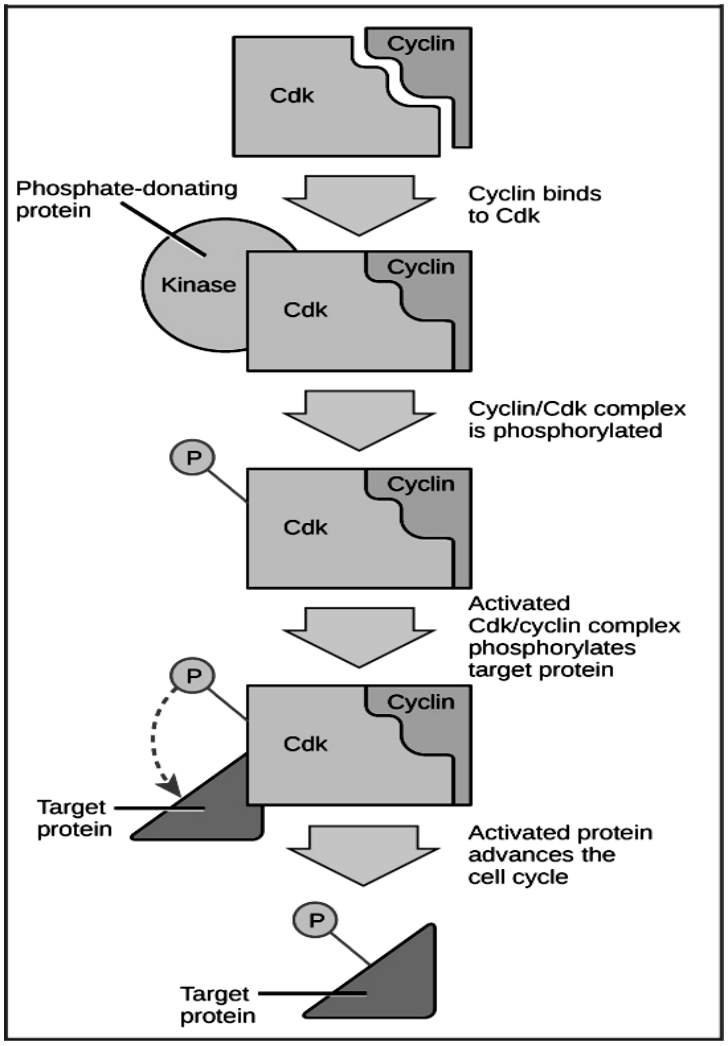

Figure-4.5: Regulation of Cyclin Dependant Kinases (Cdk) (https://tinyurl.com/3ktzdvbj)

Series of steps involved in Cdks regulation

1. Transcriptional control of cyclin genes.
2. Degradation of cyclins.
3. Transcriptional control of the cyclin subunits is one mechanism that ensures proper temporal expression of the cyclins.
4. Degradation of cyclins.

The most important regulatory control that restricts cyclins to the appropriate cell cycle stage is ubiquitin-mediated protein degradation.Cyclins are degraded through the action of two different ubiquitin-proteins:

a) SCF (Skp1,Cullin and f-box proteins)

b) APC/C (anaphase-promoting complex or cydosome)

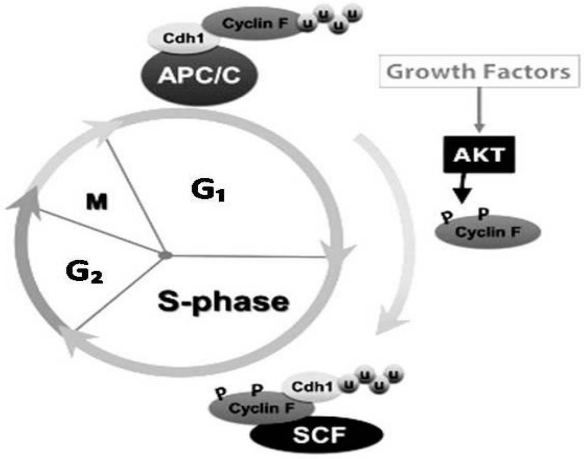

Figure-4.6: SCF regulation of cell cycle (https://tinyurl.com/36kaf57m)

The SCF complex regulates the transition from the G_1 phase to the S phase by facilitating the degradation of G_1 cyclins, specifically Cyclin D (Figure 4.6). Meanwhile, the APC/C is responsible for the degradation of S phase and mitotic cyclins, which aids in the exit from mitosis. The CDK activity is not controlled solely by cyclin levels. The presence of inhibitors, as well as activating and inhibitory phosphorylation events on the CDK subunit, is required to regulate cyclin-CDK activity.

2. Action of CDK-activating kinase (CAK): CDK activity requires threonine phosphorylation. The CDK-activating kinase (CAK) mediates this phosphorylation. The CAK activity remains consistent throughout the cell cycle and phosphorylates CDK as soon as a cyclin-CDK complex forms.

3. Inhibitory phosphorylations on CDK: CDK activity is controlled by inhibitory phosphorylation. This inhibitory phosphorylation is caused by a kinase known as "Weel".

4. Action of CDK Inhibitors: CDK inhibitors regulate Cyclin-CDK activity. CDK inhibitors, or CKIs, are a protein family that binds directly to the cyclin-CDK complex, inhibiting its activity. These proteins are very crucial in regulating the G1-S phase transition (entrance into the cell cycle).The genes encoding these CKIs are frequently found mutated in human malignancies. CKIs that regulate S phase and mitotic CDKs are all required to prevent early activation of S and M phase CDKs. Inhibitors of G1 CDKs are necessary for affecting a G1 arrest in response to proliferation inhibitory signals. Examples: INK4s, p53, p21.

4.7 CDK INHIBITORS

Cyclin-dependent kinase inhibitors (CKIs) are cyclins that are essential for controlling the cell cycle. They are proteins that work with cyclin-CDK complexes to limit kinase activity, typically during G1 or in reaction to environmental cues or damaged DNA. The two main CKI families found in animal cells are the CIP/KIP family and the INK4 family. The CDK monomers are bound by the strictly inhibitory INK4 family proteins. The crystal structures of CDK6-INK4 complexes reveal how INK4 binding distorts cyclin binding and kinase activity by twisting the CDK. Both the cyclin and the CDK of a complex are bound by the CIP/KIP family proteins, which have the ability to either activate or inhibit.

4.8 SUMMARY

The cell cycle is the process via which all cells reproduce. The cycle is made up of tightly planned and regulated molecular activities that drive the parent cell's genome replication and the separation of duplicated DNA and cytoplasm into two distinct daughter cells. The rate of cell cycling varies by developmental stage and cell type. Embryonic cells multiply to build tissues and organs, which stimulates the cell cycle the greatest. Most somatic cells in adults remain in a non-proliferative, quiescent G_0 phase, during which they are metabolically active. The cell cycle is divided into various phases. The majority of the cycle is spent in interphase, which includes Gap 1 (G_1), Synthesis (S), and Gap 2 (G_2) phases. During interphase, the cell divides, duplicates its genome, and repairs DNA damage. During the M phase, only a small portion of the cycle is devoted to the actual division of the genome and cytoplasmic contents (mitosis and cytokinesis). The cell cycle is driven by cyclin protein complexes associated to cyclin-dependent kinases (CDKs). Cyclin D-CDK4/6 and cyclin E/A-CDK2 complexes are active during G_1 and the G_1/S transitions, while cyclin A/B-CDK1 complexes promote the G_2/M transitions. Because cyclin binding is required for the activation of CDK enzymatic activity, CDKs are controlled by cyclin synthesis, degradation, and localization. CDKs are further regulated by CDK Inhibitors (CDKIs) from the INK4 and CIP/KIP families, which bind to CDKs and block activation. Cyclins, CDKs, and CDKIs are regulated by phosphorylation and ubiquitination by other molecules.

4.9 TECHNICAL TERMS

Cylclins, Cyclin dependent kinases, Cytokinesis, Mitosis, Regulation, Ubiquitin

4.10 SELF ASSESSMENT QUESTIONS

Q.1 What is the cell division? How many types of cell division occur in living organisms?
Q.2 Define the terms cell cycle and mitosis. Name the stages of mitotic cell cycle.
Q.3 What basic activities occur during mitosis?
Q.4 What is meiosis? Describe the major features of each meiotic phase.
Q.5 What are cyclins and cyclin dpendent kinases (Cdk)? Describe the role of these in cell division.

4.11 SUGGESTED READINGS

1. Cell Biology, C.B. Powar. 2010. Himalaya Publishing House, Mumbai – 400004.
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Dr. K. Babu

LESSON - 5

CELL DIVISION– MITOSIS

OBJECTIVE OF THE LESSON

Students are able to know what is cell division and role of mitotic cell division in growth and development of organisms.

STRUCTURE OF THE LESSON

5.1 INTRODUCTION

Cell division is essential to all life. In unicellular organisms, cell division is the process by which one cell produces two daughter cells to ensure lineage propagation. In multicellular animals, repeated rounds of cell division produce all of the cells needed for growth, development, homeostasis, and regeneration. Cell division must be performed with high fidelity to ensure accurate segregation of duplicated genetic material and fair physical segregation of both cytoplasmic contents and the bounding cell membrane into the new daughter cells. Failures in cell division can lead to cell death and, in the case of multicellular organisms, to the mis-segregation of genetic and cytoplasmic material, which can contribute to cancers and to developmental defects. Depending on the type of cell, there are two ways cells divide **1**. Mitosis and **2**.Meiosis. Each of these methods of cell division has special characteristics. One of the key differences in mitosis is a single cell divides into two cells that are replicas of each other and have the same number of chromosomes. This type of cell division is good for basic growth, repair, and maintenance, so it occurs in somatic or vegetative cells. In meiosis a cell divides into four cells that have half the number of chromosomes. Reducing the number of chromosomes by half is important for sexual reproduction and provides for genetic diversity. Meiosis generally occurs in generative or reproductive cells.

5.2 MITOSIS

In 1873, mitosis was documented in the corneal cells of frogs, rabbits, and cats. Subsequently, in 1875, the Polish histologist Wacław Mayzel provided the first description of mitosis. The term

"mitosis" was later introduced by the German biologist Walther Flemming in 1882. Flemming was the first to conduct a detailed observation of mitosis during the late 19th century, categorizing it into two main phases. The initial phase, termed the progressive phase, involves the condensation and alignment of chromosomes along the cell's equatorial plane. This is succeeded by a regressive phase, during which sister chromatids are separated and moved toward opposite poles of the cell. In contemporary biological studies, mitosis is recognized as comprising five critical stages: interphase, prophase, metaphase, anaphase, and telophase, with prophase being noted as one of the longest phases (Figure 5.1).

Prophase: The appearance of thin-thread-like condensing chromosomes marks the first phase of mitosis, known as prophase (Gr., pro = before; phasis = appearance). It has two stages namely Early Prophase and Late prophase.

Early Prophase: The cell becomes more spherical, refractile, and viscous. Chromosomes condense and become visible when stained. The chromosomes are made up of two identical chromatids known as sister chromatids, each carrying one DNA molecule, which are linked at the centromere. The two centrosomes that are replicated in the G2 phase right before prophase migrate to opposite poles of the nucleus. During prophase, proteins of kinetochores begin to deposit. Furthermore, during early prophase, the chromosomes are equally dispersed within the nuclear cavity.

Late Prophase: Spindle fibers (protein microtubules) begin to emerge from the centrosomes (consists of two centrioles in animal cells). There are three types of spindle fibers.

(1) Polar fibers - extend from the two poles of the spindle toward the equator
(2) Kinetochore fibers - attach to the cytoplasm,
(3) Astral fibers - radiate outward from the poles toward the periphery or cortex of cell.

As prophase continues, the chromosomes approach the nuclear envelope, leaving the center area of the nucleus vacant. Finally, during prophase, the nucleolus slowly disintegrates. The degeneration and removal of the nuclear envelope indicate the end of prophase. Two factors may be involved in this process.

1. Enzymatic action either by some mitochondrial enzymes, cytosolic MPF kinase or nuclear RNA (or ribozyme).
2. Physical action, i.e., physical stress exerted by microtubules which become attached to the nuclear envelope.

Prometaphase: The disintegration of the nuclear membrane indicates the beginning of prometaphase and allows the mitotic spindle to engage with the chromosomes.At the metaphase plate, the spindle seems to be attempting to align and confine the chromosomes. By acting as a "cap," the kinetochores help to prevent the plus end from depolymerizing. Chromosomes are held on the metaphase plate by balanced bipolar forces, whereas sister chromatids are joined to opposite poles by their kinetochores.

Metaphase: During metaphase (Gr., meta=after; phasis = appearance), the chromosomes are the shortest and thickest. Centrosomes reach opposite poles. Spindle fibers (protein microtubules) continue to extend from centrosomes. Chromosomes align along the equator of the spindle (also

known as the metaphase plate), equidistant from the two centrosome poles. Spindle fibers (protein microtubules) reach the chromosomes and bind to the centromeres. Each sister chromatid is connected to a spindle fiber that originates from opposite poles.

Anaphase: Anaphase (Gr., ana=up; phasis=appearance) begins abruptly with the simultaneous splitting of each chromosome into sister chromatids known as daughter chromosomes, each with a single kinetochore. Ca^{2+}containing membrane vesicles assemble at the spindle poles and release calcium ions, triggering anaphase. Anaphase occurs in two steps:

(i) Anaphase A: During this stage, pole ward movement of chromatids occurs due to shortening of the kinetochore microtubules. As the migration towards the poles occurs, the centromeres and kinetochores are positioned at the forefront, which causes the chromosomes to exhibit typical U, V, or J shapes.

(ii) Anaphase B: This phase involves the separation of poles themselves accompanied by the elongation of the polar microtubules. The astral microtubules also help in anaphase B by their attractive interaction with cell cortex.

Telophase: The telophase begins with the termination of the daughter chromosomes' polar movement. Mitosis is completed by the rearrangement of two new nuclei and their entry into the G1 phase of interphase. During this phase, prophase events unfold in reverse order. A nuclear envelope reassembles around each set of chromosomes, resulting in two daughter nuclei. The mitotic apparatus, with the exception of the centrioles, disappears. The high viscosity of the cytoplasm reduces. As the coils relax, the chromosomes return to their long, slender, and stretched state. RNA production resumes, causing the nucleolus to reappear.

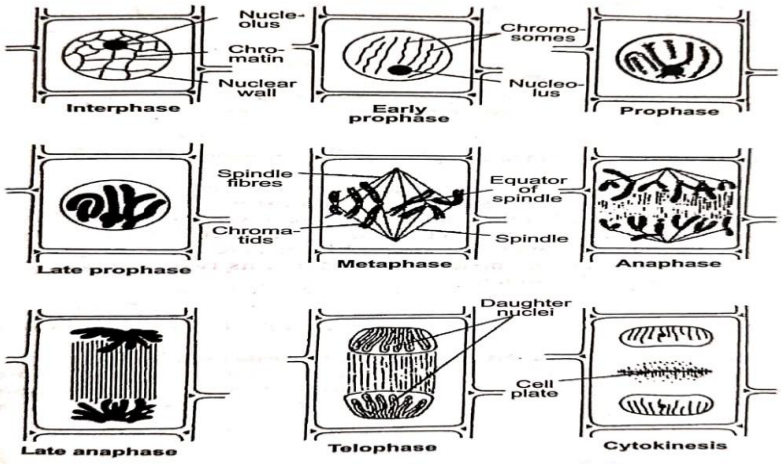


Figure-5.1: Stages of Mitosis (Verma & V. K. Agarwal, 2021)

5.3 CYTOKINESIS

Up to telophase nuclear division/karyokinesis occurs, followed by the division of cytoplasm known as cytokinesis. Cytokinesis is of two types.

1. Cell Furrow method – occurs in animals
2. Cell plate method – occurs in plants

Both DNA synthesis and mitosis are coupled to cytoplasmic division, or cytokinesis—the constriction of cytoplasm into two separate cells. During cytokinesis, the cytoplasm divides by a process, called cleavage. The mitotic spindle plays an important role in determining where and whencleavage occurs. Cytokinesis usually begins in anaphase and continues through telophase and into interphase. Karyokinesis is followed by division of cytoplasm(cytokinesis) thus forming two daughter cells.

1. Cell Furrow method: In animal cells, first sign of cleavage is puckering and furrowing of the plasma and separates daughter cells (Figure 5.2).The furrowing invariably occurs in the plane of the metaphase plate, at right angles to the long axis of the mitotic spindle. Cleavage is accomplished by the contraction of a ring composed mainly of actin filaments. This bundle of filaments, called contractile ring, is bound to the cytoplasmicface of the plasma membrane by unidentified attachment proteins. The Cell Furrow method includes **1**. The contractile ring assembles in early anaphase.**2**. This force is generated due to muscle-like sliding of actin and myosin filaments in the contractile ring. **3**. The actin-myosin interaction pulls the plasma membrane down into a furrow.**4**. When cleavage ends, the contractile ring is finally dispensed.Cytokinesis greatly increases the total cell-surface area as two cells form from one. Therefore, the two daughter cells resulting from cytokinesis require more plasma membrane than in the plant cell.Lastly, prior to cytokinesis, in M phase large membrane-bounded organelles such as Golgi apparatus and the endoplasmic reticulum break up into smaller fragments and vesicles.

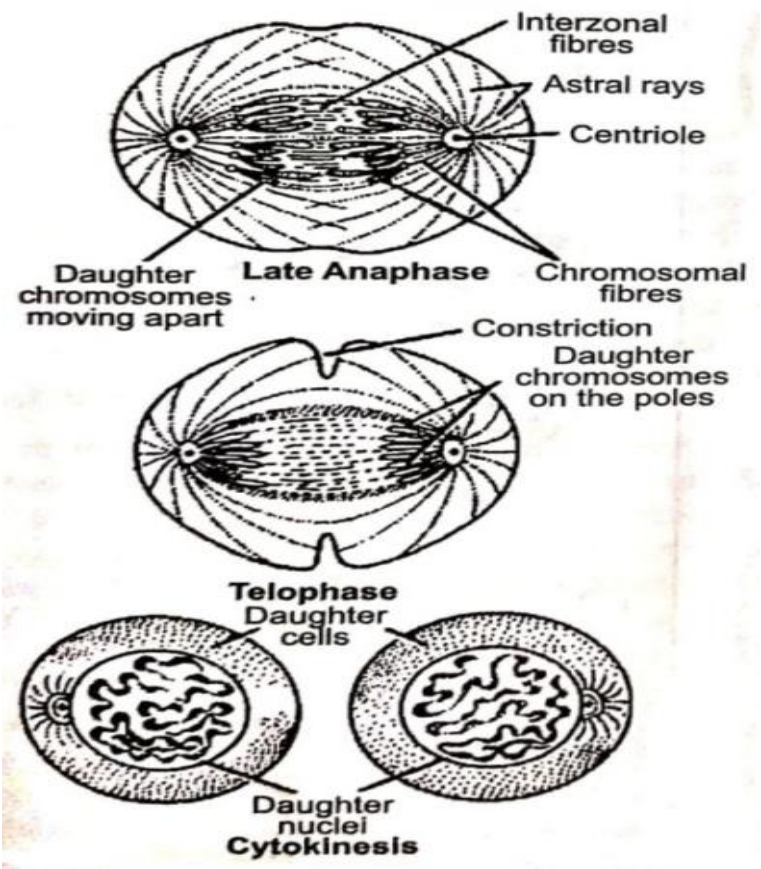


Figure-5.2: Cell Furrow method (Verma & V. K. Agarwal, 2021)

2. Cell Plate method: Due to the presence of a cell wall, cytokinesis in plant cells is significantly different from that in animal cells, Rather than forming a contractile ring, plant cells construct a cell plate in the middle of the cell (Figure 5.3). The stages of cell plate formation include (1) Creation of the phragmoplast, an array of microtubules that guides and supports the formation of the cell plate.(2) Trafficking of vesicles to the division plane and their fusion to generate a tubular-vesicular network.(3) Continued fusion of membrane tubules and their transformation into membrane sheets upon the deposition of callose, followed by deposition of cellulose and other cell wall components.(4) Recycling of excess membrane and other material from the cell plate.(5) Fusion with the parental cell wall.

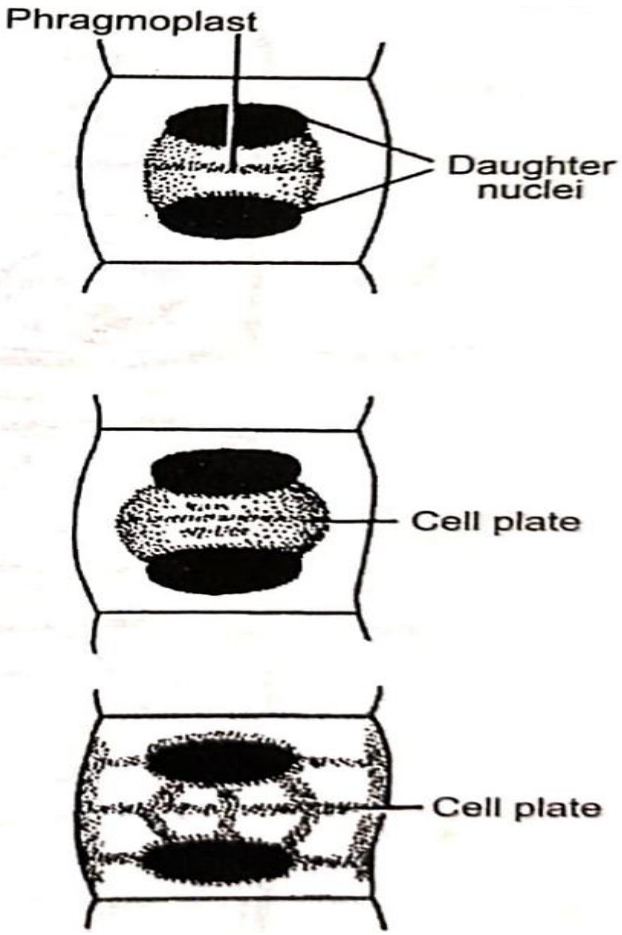


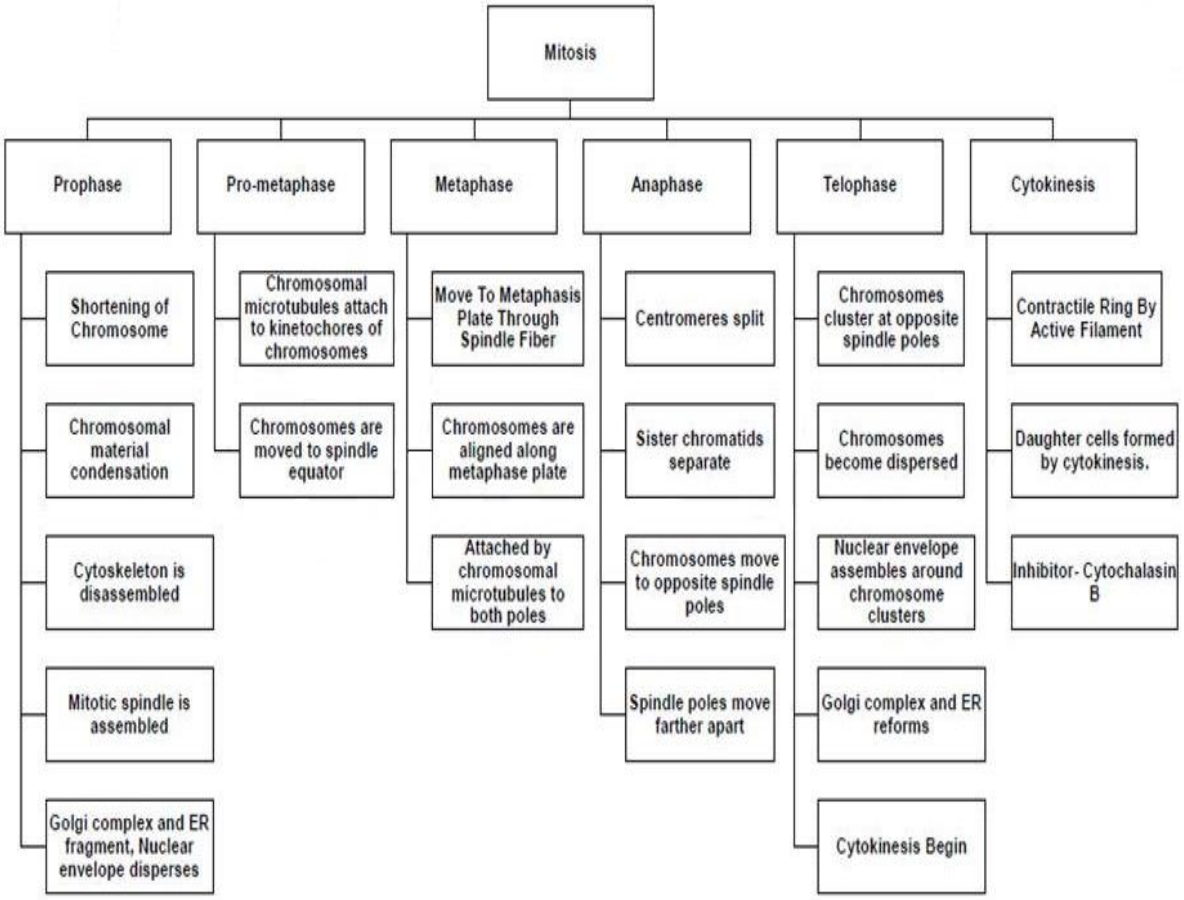
Figure-5.3: Cell Plate method (Verma & V. K. Agarwal, 2021)

Anchorage, cell density,and chemical growthfactors affect cell division

The cells within an organism's body divide and develop at different rates. Cell division is influenced externallyby **1**. The presence of essential nutrients **2**. Growth factors and proteins that stimulate the division, **3**. Density-dependent inhibition, in which the crowded cells stop dividing **4**.Anchorage dependence, the need for cells to be in contact with a solid surface to divide.

The various steps that take place in mitotic cell division are represented in Table 1.

5.4 SIGNIFICANCE OF MITOSIS



1.Growth and development: Through recurrent mitosis, a single cell zygote develops into a full-grown child (6×1022 cells). Plants can grow throughout their lives thanks to mitotic division in the apical and lateral meristems. Increases in tissue mass are caused by an increase in cell number, which is known as hyperplastic. Hence, mitosis is crucial for the growth and development of a multicellular organ.

2. Maintenance of cell size: An over-grown somatic cell is stimulated to divide, allowing mitosis to maintain a suitable surface volume ratio. It also has a high nucleo-cytoplasmic ratio, which is restored to an efficient level during division. These ratios are critical for the proper functioning of cell dispersion across all chromosomes. This promotes correct coordination among daughter cells.

3. Healing and regeneration: Mitosis produces new cells to heal wounds, and some organisms may regenerate missing parts of their bodies as well as the entire organism through mitosis.

4. Repairing: The process of replacing old or worn-out cells is known as repair. In the human body, approximately 5 ×109 cells are lost from the skin, alimentary canal lining, blood cells, and other areas. These cells are replaced by new ones created during mitosis.

5. Evidence of basic relationship: The majority of organisms have a similar mitotic mechanism, indicating fundamental similarities and relationships.

5.5 SUMMARY

Mitosis is typically defined into five stages: prophase, metaphase, anaphase, telophase, and cytokinesis. A nuclear envelope covers the nucleus during interphase, DNA replication occurs in the S phase, and sister chromatids connect at the centromere, which is located in the center of the chromosome. Centrosomes are located at each pole of the cell to arrange chromosomal movements in order to facilitate division and ensure that all material is present in both daughter cells. During mitosis, centrosomes assemble the mitotic spindle fibers, which aid in the separation of the sister chromatids. During prophase, chromatin fibers condense into chromosomes that are visible under a light microscope. Each replicated chromosome appears as two identical sister chromatids connected at their centromeres, and the mitotic spindle begins to form. Furthermore, the centrosomes begin to shift to opposing poles of the cell, propelled by the lengthening microtubules between them. The nuclear envelope separates during prometaphase, allowing microtubules to enter the nuclear region and bind to some of the chromosomes. The microtubules bind to kinetochores, which are specialized protein structures located at the centromere. Not every microtubule interacts with kinetochores. Some microtubules connect with microtubules coming from the opposite side of the cell.

In metaphase, the centrosomes have moved to opposing poles of the cell. The chromosomes have all lined up at the metaphase plate in the center of the cell, and they are all connected to microtubules via kinetochores. The metaphase plate is an imaginary line equidistant from the spindle's two poles. Anaphase is the shortest stage of mitosis, in which the sister chromatids separate and the chromosomes begin to move to opposing ends of the cell. By the end of anaphase, both half of the cell contain an equal number of chromosomes. During telophase, two daughter nuclei develop. The nuclear envelope starts to reappear. DNA begins to de-condense, and spindle microtubules start to depolymerize. Mitosis, the division of a single nucleus into two, is now complete. Finally, cytokinesis, or the split of the cytoplasm, occurs, and the cell separates into two distinct cells.

5.6 TECHNICAL TERMS

Chromatids, Centromeres, Centrosomes, Kinetochores, Microtubules, Spindle Fibers.

5.7 SELF ASSESSMENT QUESTIONS

Q.1. Describe the process of mitosis.
Q.2. Explain the methods of cytokinesis in animals and plants.
Q3. Brief the significance of mitosis.

5.8 SUGGESTED READINGS

1. Cell Biology, C.B. Powar. 2010. Himalaya Publishing House, Mumbai – 400004.
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Dr. K. Babu

LESSON - 6

CELL DIVISION – MEIOSIS

OBJECTIVE OF THE LESSON

To aware the students about the importance of meiotic cell division in transfer of parental characters to offspring and its role in the formation of gametes and in sexual reproduction.

STRUCTURE OF THE LESSON

6.1 INTRODUCTION

The process of reduced division known as meiosis (pronounced my-oh-sis) results in a halving of the amount of chromosomes per cell. Gametes are always produced in animals as a result of meiosis. Meiosis (Greek: meioum, which means to diminish or reduce) was first used in 1905 by J.B. Farmer. The word "meiosis" is derived from the Greek verb meioun, which means "to make small," suggesting that it causes the gamete cell's chromosomal count to decrease. All sexually reproducing eukaryotes, even single-celled organisms, undergo meiosis because it is necessary for sexual reproduction. Meiosis is the process of nuclear division that results in haploid cells (1N). Meiosis is similar to mitosis, but the nucleus in meiosis is diploid, and the resulting cell is haploid. To reduce the number of chromosomes to half, one cycle of meiosis consists of one cycle of chromosome duplication followed by two cycles of nuclear division, known as meiosis I and meiosis II. Meiosis is characterized by the pairing and genetic recombination of homologous chromosomes. It was first discovered and described in sea urchin eggs in 1876 by noted German biologist Oscar Hertwig (1849–1922). Belgian zoologist Edouard Van Beneden (1846–1910) described it at the chromosome level in Ascaris worms' eggs in 1883. In 1911, American geneticist Thomas Hunt Morgan (1866–1945) observed it. It is estimated that meiosis first emerged 1.4 billion years ago. Excavata is the only subgroup of eukaryotes in which meiosis is not present in every organism. However, the reproductive cycle of higher plants consists of a short, multicellular haploid stage (gametophyte) and a long dominating diploid stage (sporophyte). The sporophyte's specialized tissues are used to nurture the small gametophyte. The diploid (sporophyte) organism undergoes meiosis to produce male and female haploid cells known as spores.

6.2 KINDS OF MEIOSIS

In sexually reproducing species, meiosis takes place in the germ cells. Germ cells can be found in the gonads of both plants and mammals. Because meiosis occurs at different times in different organisms, it can be categorized as follows:

1. Terminal meiosis: It is also called gametic meiosis and commonly occurs in animals and few lower plants. In terminal meiosis, the meiotic division occurs immediately before the formation of gametes or gametogenesis.

2. Intermediary or sporic meiosis: It is the characteristic division of flowering plants. This meiosis takes place at some intermediate time between fertilization and the formation of gametes. It is also involved in the production of microspores (in anthers) and megaspores (in ovary or pistil) or in microsporogenesis and megasporogenesis.

3. Initial or zygotic meiosis: It occurs in some algae, fungi, and diatoms. Meiotic division occurs immediately after fertilization.

6.3 PROCESS OF MEIOSIS

The cells that undergo meiosis are known as meiocytes. The gonad meiocytes are known as gonocytes, and they might be spermatocytes in males or oocytes in females. The plant sporangium's meiocytes are known as sporocytes. Meiosis appears to be two mitotic divisions with no gap for DNA replication. The first meiotic division comprises a long prophase in which homologous chromosomes become closely linked and exchange genetic material. Furthermore, the first meiotic division causes a drop in chromosomal number, resulting in two haploid cells. In the first meiotic division, also known as the heterotypic division, the haploid cell divides mitotically, resulting in four haploid cells. In the second meiotic division, also known as the homotypic division, the chromosomes are not paired, the genetic material is not exchanged, and the chromosome number is not reduced. Both meiotic divisions are continuous and include the typical stages of meiosis. The prophase of first meiotic division is very significant phase because the most cytogenetical events such as synapsis, crossing over, etc., occur during this phase. The prophase 1 is the longest meiotic phase, therefore, for the sake of convenience, it is divided into six sub stages, viz., **1**. Proleptonema (proleptotene) **2**. Leptonema (leptotene) **3**. Zygonema(zygotene) **4**. Pachynema (pachytene) **5**. Diplonema (diplotene) and **6**. Diakinesis (Figure 6.1).

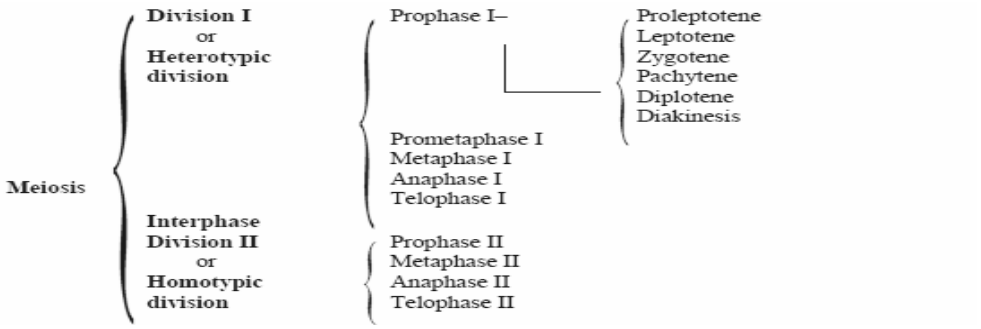

Figure-6.1: The successive meiotic sub stages

Heterotypic Division or First Meiotic Division

Meiosis occurs following an interphase that is similar to an intermitotic interphase. During the premeiotic interphase, DNA duplication occurred at the S phase. In the G2 phase of interphase, there appears to be a significant shift that drives the cell toward meiosis rather than mitosis. At the start of the first meiotic division, the nucleus of the meiocyte begins to grow by absorbing water from the cytoplasm, and the nuclear volume increases by nearly threefold. Following these alterations, the cell enters the first stage of first meiotic division, known as prophase (Figure 6.2).

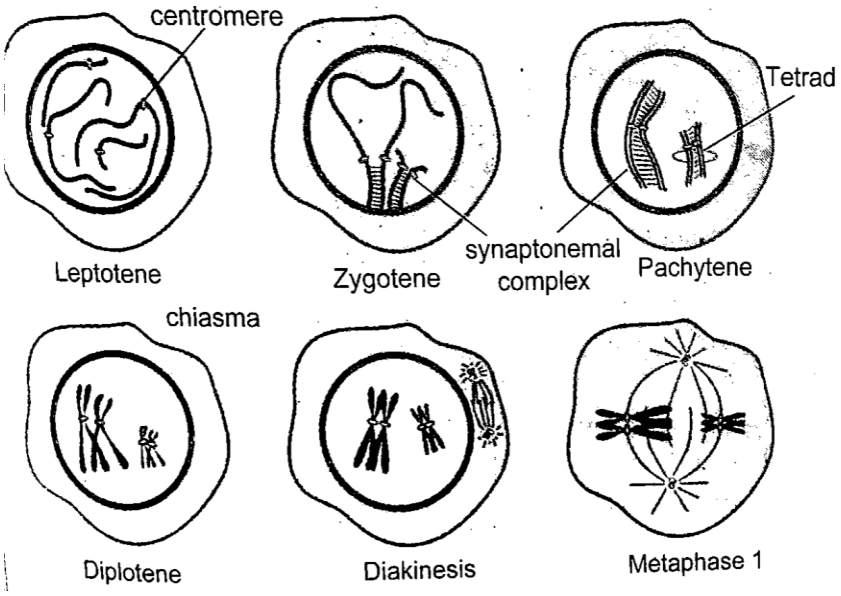

Figure-6.2: Various stages of Prophase 1 of Meiosis I (Verma & Agarwal, 2021)

Prophase I: During prophase-I, DNA is exchanged between homologous chromosomes in a process known as homologous recombination, which frequently leads to chromosomal crossover. The paired and replicated chromosomes are known as bivalents or tetrads, and the process of pairing the homologous chromosomes is known as synapsis. Non-sister chromatids may cross-over at a point known as Chiasmata.

Proleptotene or Prolepto-nema (Gr., pro=before; leptas= thin; nema= thread): The proleptotene stage is closely related to the early mitotic prophase. At this stage, the chromosomes are extremely thin, long, uncoiled, longitudinally single, slender thread-like structures.

Leptotene/Leptonema (LeptoteneGreek; Leptonema- **thin threads**): During the leptotene stage, the chromosomes become less coiled and take on a long thread-like structure. At this step, the chromosomes adopt a certain orientation within the nucleus. The chromosomal ends converge toward one side of the nucleus, which contains the centrosome (the bouquet stage). The centriole replicates, and each daughter centriole migrates to the opposite pole of the cell. When each centriole reaches the poles, it duplicates, and each cell pole now has two centrioles from a single diplosome. The two sister chromatids remain so firmly connected that they are indistinguishable from one another.

Zygotene (Greek; zygonema- paired threads)/ Zygoteneor Zygonema (Gr., zygon=adjoining): During the zygotene stage, homologous chromosomes from the mother (via ova) and father (via sperm) are attracted to each other and pair, a process known as synapsis (Gr., synapsis=union). The synapsis begins at one or more points along the length of the homologous chromosomes.

Three types of synapsis have been recognized (Figure 6.3).

(i) Proterminal synapsis: In proterminal type of synapsis the pairing in homologous chromosomes starts from the end and continues towards their centromeres.

(ii) Procentric synapsis: In procentric synapsis the homologous chromosomes start pairing from their centromeres and the pairing progresses towards the ends of the homologues.

(iii) Intermediate or Random synapsis: The intermediate type of synapsis occurs at various points of the homologous chromosomes.

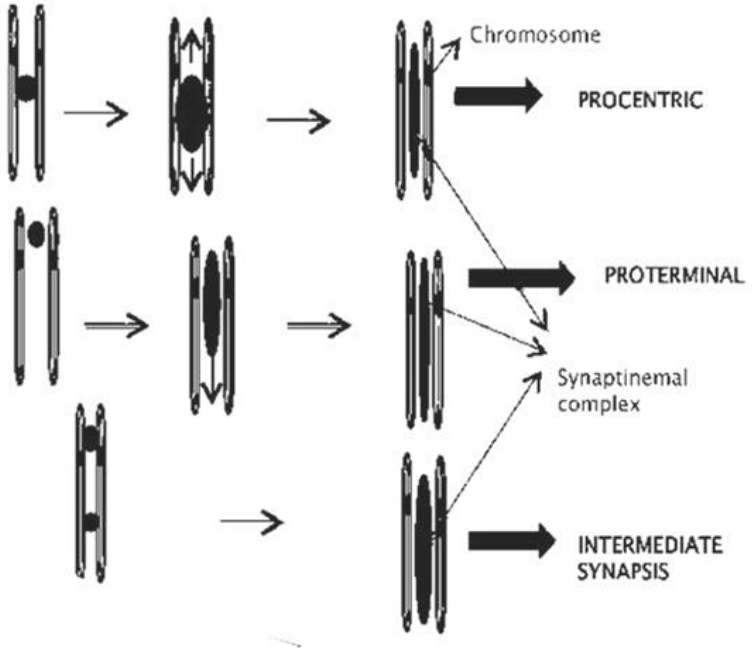

Figure-6.3: Types of synopsis occur during Prophase 1 of Meiosis I
(https://tinyurl.com/yrvvhzmu)

The paired homologous chromosomes are joined by a roughly 0.2-μm thick, protein-containing framework called a synaptonemal complex (SC) (Figure 6.4), which extends along the entire length of the paired chromosomes and is typically anchored at either end to the nuclear envelope. The SC serves to stabilize the pairing of homologous chromosomes and to facilitate the cytogenetical activity, known as recombination or crossing over (occurring during pachynema). The organisms in which crossing over does not occur do not have the SC. E.g. male fruit fly - *Drosophila melanogaster*.

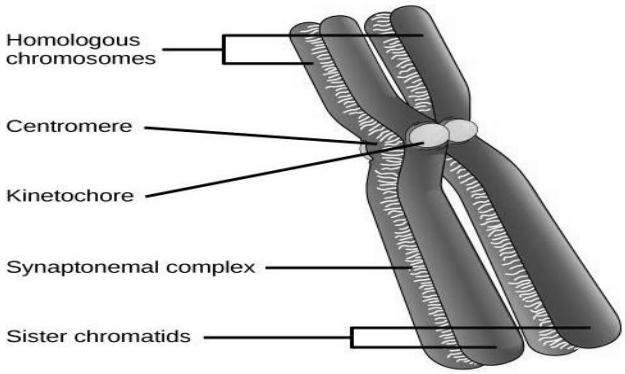

Figure-6.4: Synaptonemal complex (https://tinyurl.com/2842ppwp)

Pachytene or Pachynema (Gr., pachus=thick): During the pachynema stage, an important genetic phenomenon known as "crossing over" occurs, which involves the rearranging, redistribution, and mutual exchange of hereditary material from two parents between two homologous chromosomes. At this point, each synaptonemal pair is commonly referred to as bivalent or dyads because it consists of two visible chromosomes, or as a quadrivalent or tetrad because it consists of four visible chromatids. Recent opinions suggest that one chromatid of each homologous chromosome of a bivalent may divide transversely with the help of an enzyme called endonuclease. Following the chromatid division, chromatid segments are exchanged between the non-sister chromatids of the homologous chromosomes, and the presence of an enzyme called ligase unites the broken chromatid segments with the chromatids. This process of exchanging chromatin material between one non-sister chromatid of each homologous chromosome is called crossing over, and it is accompanied by the formation of chiasmata. During the pachytene and zygotene stages, small quantities of DNA are synthesized. This amount of DNA is used to repair broken DNA molecules in chromatids during chiasmata formation and crossing over. Up to this point, the nucleolus stays prominent and is connected with the chromosome's nucleolar organizer region.

Diplotene or Diplonema: In diplonema, homologous chromosome unpairing or desynapsis begins, and the first chiasmata appear. At this stage, the chromatids of each tetrad are usually visible, but the synaptonemal complex appears to be dissolved, leaving participating chromatids of the paired homologous chromosome physically joined at one or more discrete points known as chiasmata (singular, chiasma; Greek, chiasma=cross piece). Crossing over occurs at these locations. During this stage, the chromatids frequently unfold, allowing for RNA synthesis and cellular development.

Diakinesis: During diakinesis, the bivalent chromosomes become more evenly distributed in the nucleus, the nucleolus detaches from the nucleolar organizer and eventually disappears, the nuclear envelope degrades, and the chiasma moves from the centromere to the end of the chromosomes. This movement of the chiasmata is known as terminalization, and the chromatids remain connected by the termina.

Prometaphase: During prometaphase, the nuclear membrane disintegrates and microtubules form a spindle between the two centrioles, which serve as the cell's two opposed poles. The chromosomes coil tightly in a spiral pattern and are positioned on the spindle's equator.

Metaphase I: Chromosome alignment at the equator and spindle fiber attachment to chromosomes comprise metaphase I. The centromeres of each tetrad's homologous chromosomes are joined to the spindle's microtubules during metaphase I. Every chromosome has a centromere that faces the opposing poles. The homologous chromosomes become more repelled of one another and are prepared to split apart.

Anaphase I: At anaphase I, homologues are separated and, as chromosomal fibres or microtubules shorten, each homologous chromosome, with its two chromatids and undivided centromere, moves towards the opposite poles of the cell. This is where the actual reduction and disjunction occur. It should be noted that homologous chromosomes that move to opposite poles are either paternal or maternal in origin. During the formation of a chiasma between two chromatids of a chromosome, one of the chromatids changes its counterpart; thus, the two chromatids of a chromosome are genetically distinct.

Telophase I: The onset of telophase I is marked by the arrival of a haploid set of chromosomes at each pole, during which time the nuclei are reassembled, the endoplasmic reticulum forms the nuclear envelope around the chromosomes, the chromosomes uncoil, the nucleolus reappears, and two daughter chromosomes are formed. Following karyokinesis, cytokinesis takes place, resulting in the formation of two haploid cells, both of which go through a brief resting phase of interphase, during which no DNA replication takes place, leaving the chromosomes at the second prophase identically double-stranded.

Cytokinesis: Often, cytokinesis occurs after Meiosis II rather than after Meiosis I. If the meiosis I cell goes through cytokinesis, the cell membrane constricts, and two daughter cells are created. These progeny cells have a chromosome made up of one of their original chromatids and another made up of segments from their own and a chromatid from their homologue.

Homotypic or Second Meiotic Division

The mitotic division that splits each haploid meiotic cell into two haploid cells is actually the homotypic or second meiotic division (Figure 6.5); the only difference is that the centromeres duplicate while the DNA does not. Meiosis II, also known as the mitotic or equational phase, consists of the following four stages.

Prophase II: Each centriole splits in half during the second prophase, creating two pairs of centrioles. Every centriole pair moves to the pole on the other side. The microtubules form a spindle-like arrangement. Both the nucleolus and the nuclear membrane vanish. The two-chromatid chromosomes became thicker and shorter.

Metaphase II: During metaphse II, the chromosomes get positioned on the equator of the spindle. The centromere separates into two and, thus, each chromosome creates two monads or daughter chromosomes. The microtubules of the spindle are associated with the centromere of the chromosomes.

Anaphase II: The daughter chromosomes move towards the opposite poles due to the shortening of chromosomal microtubules and stretching of inter zonal microtubules of the spindle.

Telophase II: Reconstitution of nuclei takes place. The chromosomes begin to uncoil and become thin. Nucleolus and nuclear membrane reappear.

Cytokinesis: Cytokinesis of the daughter cells causes the formation of two cells, in other words from the two daughter cells of the first meiotic division, four cells are produced each with haploid set of chromosomes.

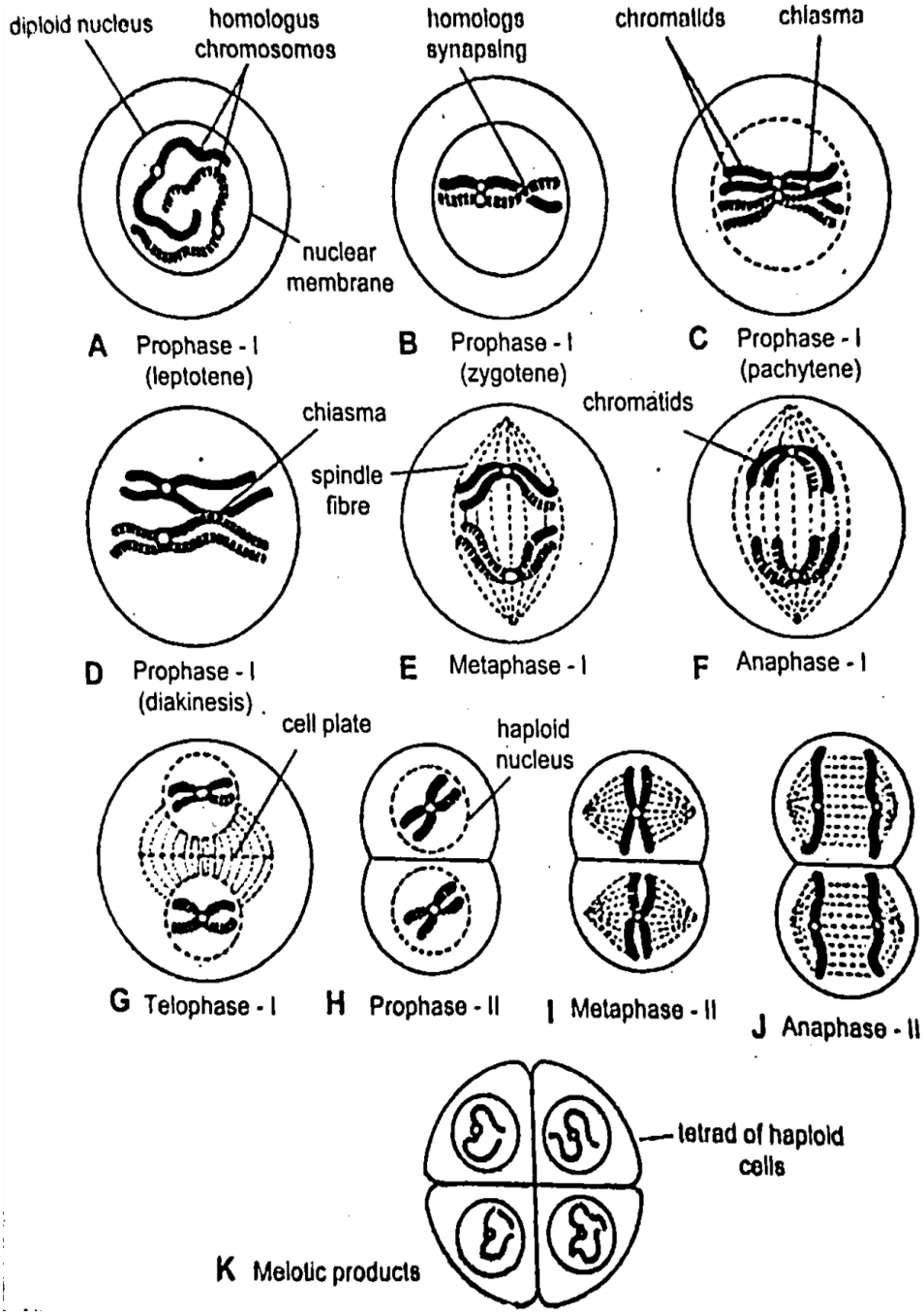

Figure-6.5: Various stages of Heterotypic and Homotypic Meisois (Verma & Agarwal, 2021)

6.4 SIGNIFICANCE OF MEIOSIS

1. Meiosis is responsible for the formation of sex cells or gametes that are responsible for sexual reproduction.
2. It activates the genetic information for the development of sex cells and deactivates the sporophytic information.
3. It maintains the constant number of chromosomes by halving the same. This is important because the chromosome number doubles after fertilization.
4. In this process independent assortment of maternal and paternal chromosomes takes place. Thus the chromosomes and the traits controlled by them are reshuffled.
5. The genetic mutation occurs due to irregularities in cell division by meiosis.
6. The mutations that are beneficial are carried on by natural selection.
7. Crossing over produces a new combination of traits and variations.

6.5 SUMMARY

Meiosis is the process of cell division in reproductive cells. This two-phase procedure splits the chromosomes of a diploid germ cell, resulting in four haploids. During prophase I, the nuclear envelope begins to break down and nuclear chromatin begins to condense into individual chromosomes composed of two sister chromatids. During metaphase I, pairs of homologous chromosomes (known as tetrads) migrate along their microtubule attachments, lining up along the metaphase plate. Anaphase I is the following stage, in which the homologous chromosome attachments break down and kinetochores pull the homologous chromosomes to opposing poles. Telophase and cytokinesis are the final stages of meiosis I, when the cells separate into two daughter cells. Prophase II is the first stage of meiosis II, in which the nuclear envelope degrades and the spindles regenerate. In metaphase II, the chromosomes align along the metaphase plate. Sister chromatids (individual chromosomes when separated) travel to opposing poles of the meiotic spindle during anaphase II. The chromosomes reach the poles in the final stage of meiosis II, the spindle disintegrates, and the nuclear envelopes reconstitute. Cytokinesis divides the original diploid cell into four haploid daughter cells.

6.6 TECHNICAL TERMS

Chaismata, Crossing Over, Haploid, Homologous, Recombination.

6.7 SELF ASSESSMENT QUESTIONS

Q1. Describe in detail the various stages of Prophase 1 of Meiosis I.
Q2. Explain heterotypic meiotic division.
Q3. Write a note on Homotypic meiotic division.
Q4. Explain the significance of meiosis.

6.8 SUGGESTED READINGS

1. Cell Biology, C.B. Powar. 2010. Himalaya Publishing House, Mumbai – 400004.
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3. Cell Biology, Genetics, Molecular Biology, Evolution and Ecology. P.S. Verma & V. K. Agarwal, 2021. S.Chand And Company Limited, New Delhi – 110044.

Dr. K. Babu

LESSON – 7

CYTOSKELETON OF EUKARYOTIC CELL

OBJECTIVE OF THE LESSON

To make the students to understand the cytoskeleton structure, types, and its functions in cell shape, structure and cellular movements.

STRUCTURE OF THE LESSON

7.1 INTRODUCTION

The cytoskeleton, a network of filamentous proteins, allows a cell to keep its shape, transport its cargo, and move. Cellular mobility includes both intracellular organelle movement and cell division. The cytoskeleton consists of tiny filamentous proteins. The cytoskeleton is responsible for eukaryotic cells' capacity to change shape and perform coordinated and controlled movements. The bacteria appear to lack a cytoskeleton, which may have played an important role in the evolution of eukaryotic cells. Koltzoff proposed the existence of an ordered fibrous array or cytoskeleton in the protoplasm in 1928. The cytoskeleton extends into the cytoplasm and is a complicated network comprising three types of protein filaments. 1. Microtubules 2. Microfilaments (actin filaments) and 3. Intermediate filaments (IFs). The cytoskeleton contains the following proteins: tubulin in microtubules, actin, myosin, tropomyosin in microfilaments and keratins, vimentin, desmin, and lamin in intermediate filaments. Actin and tubulin are globular proteins, whereas intermediate filament components are fibrous proteins.

7.2 MICROTUBULES

Microtubules were first observed by Robertisand Franchi (1953). The exact nature of microtubules was brought by Sabatini, Bensch and Barnett (1963). Microtubules of plant cells were first described in detail by Ledbetter and Porter (1963).

Occurrence

All eukaryotic cells include microtubules, either free in the cytoplasm or as part of centrioles, cilia, and flagella. Microtubules are found in the cytoplasm of animal and plant cells, specifically in 1. Cilia and flagella. 2. Centrioles and basal bodies. 3. Neurons 4. The mitotic

apparatus 5. The cortex of meristematic plant cells 6. Cells that elongate, such as during lens development or spermatogenesis in certain insects 7. Few structures in Protozoa.

Structure

Microtubules are a group of morphologically and chemically similar filamentous rods found in both plant and animal cells. A microtubule is a long, unbranched, hollow tube 24-25 nm in diameter, several micrometers long, with a 6 nm thick wall and 13 subunits or protofilaments (Figure 7.1). Tubulin is a protein that forms the protofilament of microtubules. Tubulin comes in two forms: α-tubulin and β-tubulin, both containing around 450 amino acids. Tubulin in the form of dimers polymerizes into microtubules. Several proteins have recently been identified as interacting with the surface of microtubules. These proteins are known as microtubule-associated proteins, or MAPs. The following two primary types of MAPs have been isolated:1. HMW proteins with molecular weights between 200,000 and 300,000 2. Tau proteins have molecular weights ranging from 40,000 to 60,000.

Cytoplasmic microtubules are extremely dynamic structures that constantly emerge and disappear in response to cellular processes. The polymerization (assembly) and depolymerization (disassembly) of microtubules appear to be a type of self assembly. The assembly of microtubules from tubulin dimers is a carefully planned and directed process. The amount of polymerized tubulin is highest in interphase (cytoplasmic microtubules) and metaphase (spindle microtubules), but lowest in prophase and anaphase. Within the cell, microtubules and free tubulin are in equilibrium. Phosphorylation of tubulin monomers by a cyclic AMP-dependent kinase promotes polymerization. A significant association has been discovered between cell shape, the number and direction of microtubules, and cAMP. Tubulin assembly and disassembly are polarizing phenomena. Tubulin dimers are assembled at one end of a microtubule, and disintegration occurs at the other. Certain medications, including as colchicine, vincristine, and vinblastine, block microtubule assembly. Furthermore, the assembly is accompanied by the hydrolysis of guanosine triphosphate (GTP) to guanosinediphosphate (GDP), and the assembly is terminated when GTP is not present.

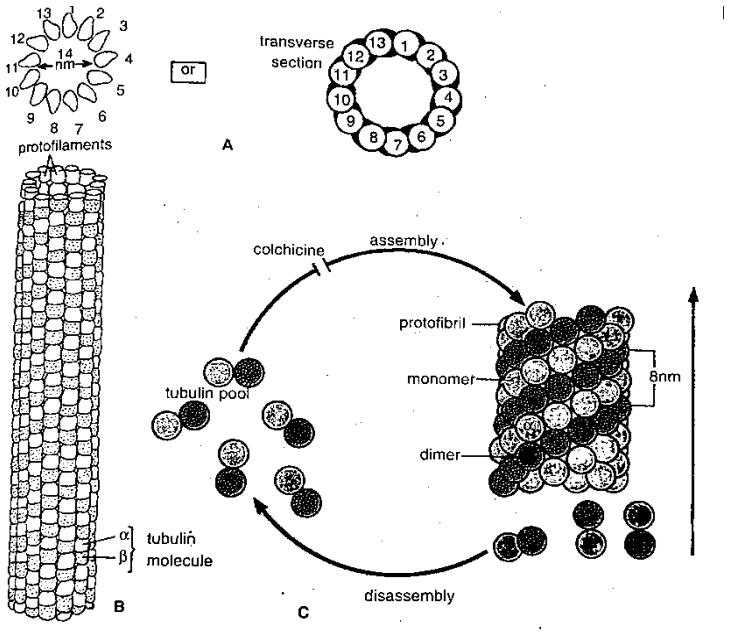

Figure-7.1: Schematic diagrams of a microtubule

A. Tubulin molecules (subunits of protofilaments) in cross section.
B. Side view of a short section of a microtubule.
C. Assembly and disassembly of the microtubule
(Alberts *et al.*, 1989).

Functions of Cytoplasmic Microtubules

Microtubules have several functions in the eukaryotic cells such as follows:

1. Mechanical function: The shape of the cell and some cell processes or protuberances such as axons and dendrites of neurons, microvilli, etc., have been correlated to the orientation and distribution of microtubules.
2. Morphogenesis: During cell differentiation, the mechanical function of microtubules is used to determine the shape of nucleus of the spermatid during spermiogenesis, the elongation of the cells during induction of the lens placode in the eye.
3. Cellular polarity and motility: The determination of the intrinsic polarity of certain cells is also related to the microtubules. Directional gliding of cultured cells is found to depend on the microtubules.
4. Contraction: Microtubules play a role in the contraction of the spindle and movement of chromosomes and centrioles as well as in ciliary and flagellar motion.
5. Circulation and transport: Microtubulesare involved in the transport of macromolecules, granules and vesicles within the cell.

7.3 MICROFILAMENTS

Microfilaments are actin-based cytoskeleton fibers (Figure 7.2). Actin is one of the most abundant proteins in eukaryotic cells, accounting for 20% of all cellular protein by weight in muscle cells. Microfilaments are typically found in the cortical areas of the cell, immediately beneath the plasma membrane. Microfilaments also penetrate cell processes, particularly where there is mobility. As an example, consider microvilli. Actin is the primary structural protein in microfilaments. There are three types of actins: α, β, and γ. Fully mature muscular tissue contains α-actin. The other two kinds are more typical of non-muscle cells. Actin amino acid sequences are largely conserved in eukaryotic cells. Actin can exist as a free monomer called G-actin (globular) or as a polymer microfilament termed F-actin ("F" for filamentous). Actin must be coupled to ATP in order to assemble into filaments and retain their structural integrity. The actin filament possesses structural polarity. The term "polarity" refers to the filament's two different ends. These ends are referred to as the "(-)" and "(+)" ends. Actin subunits are added to the elongating filament at the "(+)" end, whereas they are disassembled or fall off at the "(-)" end. The ATP to ADP conversion controls the process of assembly and disassembly.

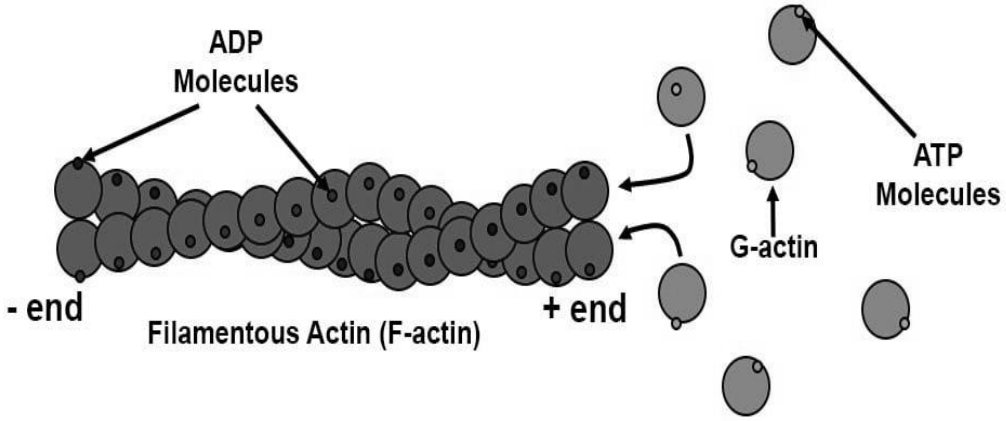

Figure-7.2: Microfilament structure (https://bit.ly/4hrNdkZ)

Functions

1. Microfilaments are the part of muscle cells and allow these cells to contract, along with myosin.
2. Actin and myosin are the two main components help in the contraction of muscles.
3. They play role in cell migration via lamellipodia and filopodia, amoeboid movement, cytoplasmic streaming.
4. The parallel bundles of microfilament form the microvilli.
5. They produce cleavage furrows that divide the cytoplasm of cell during cytokinesis. Help to maintain the cell shape.

7.4 INTERMEDIATE FILAMENTS

Most of the eukaryotic cells cytoplasm contains durable and resilient protein fibers known as intermediate filaments (IFs). They are usually between 8 and 10 nm in diameter, which is "intermediate" between thin and thick filaments. IFs are resistant to colchicine and cytochalasin B, but are vulnerable to proteolysis. The intermediate filaments have been given several names, which are based on the cell type in which they are detected. Thus, IFs in epidermal cells are known as tonofilaments, in nerve cells as neurofilaments, and in neuroglial cells as glial filaments. In cross-section, intermediate filaments seem tubular. Each tubule appears to be composed of four or five protofilaments stacked in parallel. IFs are composed of polypeptides of about 40,000 to 130,000 daltons.

Types of intermediate filaments

The intermediate filaments aregrouped into followingfour main types based on their morphology and localization.

1. Type I IF proteins: They are found mostly in epithelial cells and include two keratin subfamilies (cytokeratin). 1. Acidic keratin; 2. Neutral or Basic keratin. Keratin filaments are always heteropolymers composed of an equal number of subunits from both of these keratin subfamilies. Keratins are the most complicated class of IF proteins, with 19 different forms in human epithelia and another 8 in hair and nail keratins.

2. Type II IF proteins: These polypeptides are classified into four different categories. 1. Videtin 2. Desmin 3. Synemin and 4. Glial filaments also known as glial fibrillary acidic proteins. Fibroblasts, blood vessel endothelial cells, and white blood cells are all rich in

vimentin. Desmin exists in both striated and smooth muscle cells. Astrocytes and Schwann cells both have glial filaments. Synemin, desmin, and vimentin are all found in muscle intermediate filaments.

3. Type III IF proteins: The IF proteins are known as neurofilament proteins because they form neurofilaments, which are an important cytoskeletal component of nerve axons and dendrites. The three different polypeptides that make up Type III IFs in vertebrates are referred to as the neurofilament triplet.

4. Type IVIF proteins: They are the **nuclear lamins** which form highly organized two dimensional sheets of filaments. These filaments rapidly disassemble and reassemble at specific stage of mitosis.

General Structure of Ifs

All cytoplasmic IF proteins are encoded by members of the same multigene family, despite the wide variations in size. A similar central section consisting of approximately 310 amino acid residues forms a prolonged α helix with three brief α-helical interruptions, according to their amino acid sequences.

Assembly of IFs

The following steps are included in a current model of intermediate filament assembly: 1. A dimer is formed by the pairing of two identical monomers, with the conserved helical core sections oriented in parallel and twisted into a coiled coil. 2. Two dimers then align themselves side by side to create a protofilament with four polypeptide chains that measures 48 nm by 3 nm. 3. Subsequently, these protofilaments form progressively larger structures by staggered association. 4. The intermediate filament's final 10 nm diameter is believed to be made up of eight protofilaments that are linked end on end to their neighbours by staggered overlap to create the long, rope-like filaments (Figure 7.3).

IFs during Mitosis

Vimentin and cytokeratin intermediate filaments undergo dramatic alterations throughout the mitosis of cultured epithelial cells. The 10 nm filaments unwind into 2–4 nm threads and spheroidal aggregates with both kinds of proteins during prophase. The filamentous cytoskeleton gradually re-establishes during telophase, whereas the majority of vimentin and cytokeratin emerge as spheroid entities during metaphase and anaphase.

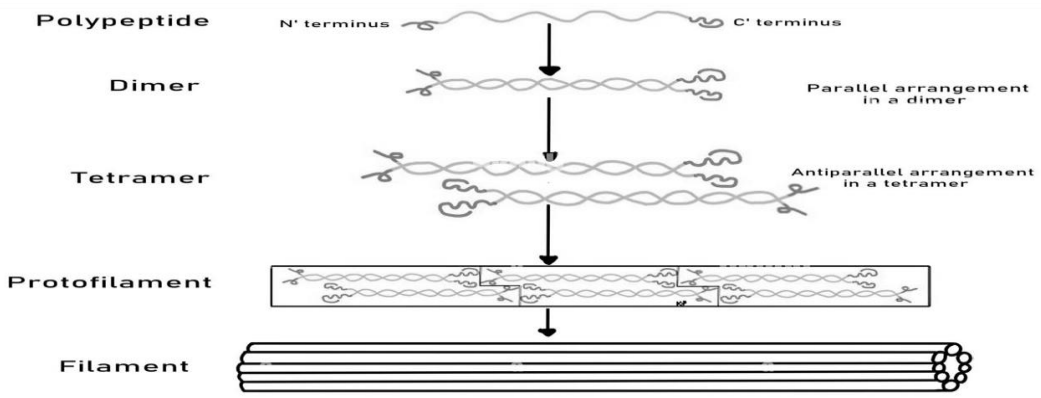

Figure-7.3: Assembly of Intermediate filaments (https://bit.ly/4jGUOhN)

Functions of IFs

1. The intermediate filaments in the cytoplasm maintain the cell's shape, bear tension, and provide structural support to the cell.
2. Fix the organization of certain cell organelles.
3. Intermediate filaments organize the internal tridimensional structure of the cell, anchoring organelles and serving as structural components of the nuclear lamina.
4. Keratin intermediate filaments in epithelial cells provide protection for different mechanical stresses that skin may endure.
5. They also provide protection for organs against metabolic, oxidative, and chemical stresses.
6. Strengthening of epithelial cells with these intermediate filaments may prevent onset of apoptosis, or cell death, by reducing the probability of stress.
7. In combination with proteins and desmosomes, the intermediate filaments form cell-cell connections and anchor the cell-matrix junctions that are used in messaging between cells.

The Arrangement of cytoskeleton filaments at cellular level was given in figure 7.4.

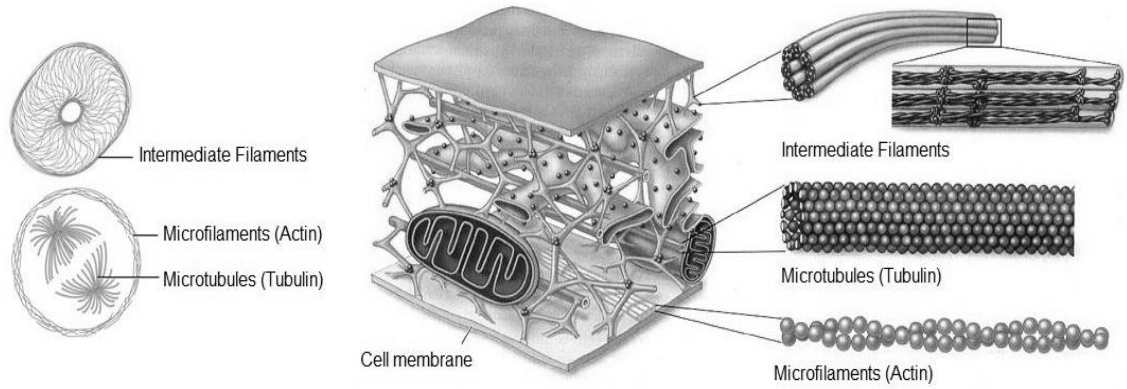

Figure-7.4: Arrangement of cytoskeleton filaments at cellular level (https://bit.ly/4h3oWSI)

7.5 SUMMARY

Cell is the basic unit of life. Study of the cell is called cytology. In today's lecture we studied about Cytoskeleton. We will break cytoskeleton into two parts: "Cytos" + "Skeleton". Cyto means Cell and Skeleton means the framework. So the Cytoskeleton provides the architecture or framework for which the entire cell is able to support itself and to quickly revise three subclass of Cytoskeleton. They are (A) Microtubule (B) Microfilament (C) Intermediate Filament. The microtubules are made up of α- tubulin and β- tubulin arranged alternately to form a protofilament. The microtubule is to promote scaffold formation, gives shape to the cell and this is what contributes to the various shapes of the eukaryotic cells. Microfilament or Actin filaments are chiefly found in the skeletal muscle cells. The microfilament also called as actin filament is solid rod of protein formed¬ by two strands of actin filament and it shows spiral arrangement. The intermediate filaments are made up of different types of proteins like keratin, desmin, lamin and vimentin. Intermediate filaments are extremely strong, durable and round protein filament present entirely across the cytoskeleton, found chiefly in those cells subjected to mechanical stress. It is classified into keratin filament, lamin filament, neurofilament, and Type III Intermediate Filament. All these cytoskeletal elements perform many functions like maintain the cell structure, acts as supporting framework, help in cell movement, intracellular transport of material, locomotion and fix the organization of cell organelles.

7.6 TECHNICAL TERMS

Microtubule, Microfilament, Intermediate filaments, Tubulin, Actin, Keratin, Desmin, Lamin and Vimentin.

7.7 SELF ASSESSMENT QUESTIONS

Q1. Describe the structure and functions of microtubules.
Q2. Explain the structure of microfilaments and their types? Add a note their role in cellular motility.
Q3. Give a detailed analysis on intermediate structures of cytoskeleton and their significance in cell structure and shape.

7.8 SUGGESTED READINGS

1. Cell Biology, C.B. Powar. 2010. Himalaya Publishing House, Mumbai – 400004.
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Dr. K. Babu

LESSON – 8

GENERAL ACCOUNT AND THALLUS ORGANIZATION OF ALGAE

OBJECTIVE OF THE LESSON

Students are able to know the history of phycology. Understand about the algal habitats and the algal thallus organization from single cell to complex thalli.

STRUCTURE OF THE LESSON

8.1 INTRODUCTION

Algae comprise a group of chlorophyll containing thalloid plants of the simplest type, having no true roots, stems, leaves or leaf like organs known as Thallophyta ((Gr. thallos — a sprout; phyton — a plant). The term algae (Latin — seaweeds) was first introduced by Linnaeus in 1753, meaning the Hepaticeae. The term Algae (L. alga- seaweed) is collectively used for all the Chlorophyll bearing nonvascular thalloid organisms. Linnaeus (1754) first coined the term algae, which he placed along with Liverworts (Hepaticae) and lichen under class Cryptogamia of Plant-Kingdom. The systematic study of algae is called Phycology (Gr. phycos — seaweeds; logos — study or discourse) Algology (L. alga – sea weed; logos – study or discourse). This division comprises both prokaryotic and eukaryotic, with wide range of thalli starting from unicellular simple (1μ) to multicellular large (60 m) sea weeds. Algae, commonly known as pond scum, can be seen easily growing on water surface of ponds, ditches, tanks, pools, etc. Algae can be defined as a group of autotrophic, non-vascular thalloid plants having unicellular or multicellular, non-jacketed sex organs with no embryo formation. The references of algae are available in ancient literature of Greek, Roman and Chinese. F.E. Fritsch is known as 'Father of Algology' and M.O.P. Iyenger is known as the 'Father of Modern Algology of India'.

8.2 HABITAT

Algae are inhabiting in a variety of habitats and they are found in a variety of habitats, such as freshwater, sea water, on snow, on rocks and on/or within the plant and animal bodies, terrestrial, cryophytic, parasitic, endophytic, thermophytic, halophytic etc (Figure 8.1). Of these, aquatic forms are most common. On the basis of habitat, they may be classified into the following three groups:

(1) Aquatic algae

(2) Terrestrial algae

(3) Algae of unusual habitats

1. Aquatic algae

Aquatic algae may be fresh water (when salinity is as low-as 10 ppm) or marine (when salinity is 33-40%). Again, certain algae grow in brackish water which is unpalatable for drinking, but less salty than sea water. The fresh water algae usually grow in ponds, lakes, tanks, ditches etc. Based on their aquatic habitat these are of two types i. Fresh water forms ii. Marine forms.

i. Fresh water forms: Fresh water algae may be termed as planktonic when they grow and remain suspended on the upper part of water (e.g., Volvox, Diatom), while the benthic algae are bottom dwellers. The algae that grow at air-water interface are called neustonic. The benthic algae may be epilithic (grow on stones), epipelic (attached to sand or mud), epiphytic (growing on plants), and epizoic (growing on animal body surface). These forms occur in fresh water (salinity 10 ppm) of ponds, pools, lakes, rivers, etc. Some fresh water forms like Cladophora, Oedogonium, Ulothrix and Chara are found in slow running water, whereas Chlamydomonas, Volvox, Hydrodictyon and Spirogyra occur in stagnant water. The very common fresh water algae are Chlamydomonas, Volvox, Ulothrix, Chara, Oedogonium, Spirogyra, Nostoc, Oscillatoria etc.

ii. Marine forms: Marine algae are found in salty water of sea and oceans. These forms occur in saline water of the sea and are represented by the members of Phaeophyceae (e.g. Ectocarpus, Sargassum, Fucus) and Rhodophyceae (e.g. Polysiphonia). Marine algae have macroscopic thalli and are generally considered as ‘sea weeds’. The marine algae may be supralittoral or sub- aerial (grow above the water level and in the spray zone). The intertidal algae grow in such a depth so that they are exposed periodically due to tides. Other marine algae are sublittoral, meaning that they are constantly submerged at depths as great as 30-60 metres (100-200 ft). Again, the supralittoral algae may be edaphic (grow in and on the soil), epilithic (growing on stones), epiphytic (growing on plants), epizoic (growing on animal body surface), and corticolous (growing on tree barks and parasitic on plants and animals. Some algae (e.g., Chlorella) live endozoically in various protozoa, coelenterates, molasses etc. Many algae are found attached to rocks along the edges of lakes and seas and these forms are called phytobenthos. Some of the very common marine algae are Sargassum, Laminaria, Ectocarpus, Polysiphonia, Caulerpa, Bangia, Padina etc.

2. Terrestrial algae

Some algae are found to grow in terrestrial habitats like soils,' rocks, logs etc. The algae that grow on the surface of the soil are known as saprophytes. Many blue-greens, on the other hand, grow under the surface of the soil, and are called cryptophytes. The algae growing in the desert soil may be typified as edaphic (living in soil), epidaphic (living on the soil surface), hypolithic (growing on the lower surface of the stones on soil), chasmolithic (living in rock fissures) and endolithic algae (which are rock penetrating). The common terrestrial members are Oscillatoria sancta, Vaucheria geminata, Chlorella lichina, Euglena sp., Fritschiella sp. and Phormidium sp.

3. Algae of unusual habitats

In addition to aquatic and terrestrial habitats, some algae also occur in uncommon habitats.

a) Cryophytic algae (snow): Algae growing on ice or snow are called cryophytic. These algae provide attractive colours to snow covered mountains. The alpine and arctic mountains become red due to the growth of Haemotococcus nivalis. Green snow in Europe is due to Chlamydomonas yellowstonensis and species of Mesotaenium. Sometimes snow becomes black due to Scotiella nivalis and Raphidonema brevirostri and brownish purple due to Ancyclonema nordenskioldi.

b) Thermophytes (Thermal algae): Many bluegreen algae (e.g. Oscillatoria brevis, Synechococcus elongatus, Heterohormogonium sp. Haplosiphon lignosum) are found in hot water springs (50-70° C). They are able to survive such high temperatures due to the absence of well organised nucleus. Since most hot springs are alkaline, some algologists believe that tolerance to high temperature is also associated with this factor.

c) Halophytic algae: There are many algae which occur in saline water of seas, but some others can withstand high concentration of salts and. in salt lakes. They are called halophytes, include Chlamydomonas ehrenbergii, Dunaliella and Stephanoptera.

d) Lithophytic algae: Algae growing on moist rocks and stones are known as lithophytic. Many blue-green algae like Nostoc, Rivularia and Gloeocapsa commonly grow on moist and rocks. Scytonema shady is common on moist walls during rainy season.

e) Epiphytic algae: They grow on larger algae or on bryophytes and angiosperms. For example species of Bulbochaete, Oedogonium and Microspora are found attached to the larger species of Cladophora, Rhizoclonium. Bryophytic and angiospermic flora of rivers and lakes harbour many algal members on their surface Algae with mucilagenous thalli like Chaetophora, Oedogonium and Achnanthes, Eunotia, Synedra etc.

f) Epizoic algae: Many algae grow on animals like snails, fishes and tortoise, and they are known as epizoic. E.g. Cladophora crispata grows on snails, and species of Stigeoclonium are found in the gills of fishes. Similarly, species of Characiopsis and Characium are found on the legs of Branchipus.

g) Endozoic algae: Algae which occur in the tissues of animals are known as endozoic. For example. Species of Zoochlorella are found in Hydra viridis. Besides, several species of the family Oscillatoriaceae (blue-green algae) occur in the respiratory and digestive tracts of vertebrate animals.

h) Symbiotic algae: Chlorophyceae and Cyanophyceae form symbiotic association with fungi, bryophytes. Gymnosperms and angiosperms. Lichens are imnportant example of symbiotic life and their algal components belong to Cyanophyceae (e.g. Nostoc, Gloeocapsa, Microcystis) or Chlorophyceae (e.g. Coccomyxa, Protococcus). Colonies of

Nostoc and Anabaena are found in symbiotic association in the thallus of Anthoceros and the coralloid roots of Cycas.

i) **Parasitic algae:** Algae also grow as parasites on many plants and animals. Cephaleuros virescens (Chlorophyceae) causes red rust in tea and coffee plantations, parasite on the leaves of Arisarum vulgare. Polysiphonia fastigiata semiparasite on Ascophyllum nodosum.

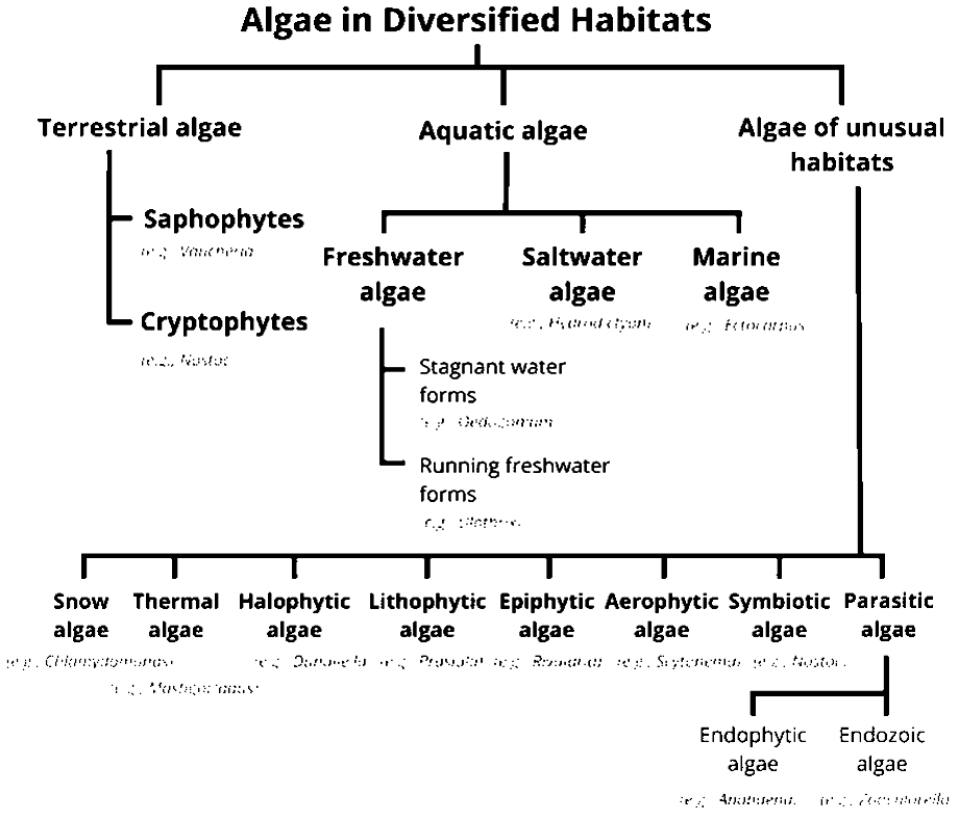

Figure-8.1: Flow chart of Algal habitats

8.3 THALLUS ORGANIZATION

The vegetative thallus of algae exhibits a diverse range of forms, encompassing both unicellular and multicellular types, with sizes varying from mere microns to several meters. Micromonas pusilla is recognized as the smallest alga approximately 1 μm and giant kelps are largest algae (60 m). Unicellular algae may exist as single and capable of completing their life cycles independently, fulfilling all necessary physiological, biochemical, and genetic functions, and can be either motile or non-motile. When these unicellular organisms aggregate within a shared gelatinous matrix, they form colonial structures, which represent a transitional form between unicellular and multicellular organization. Additional intermediate forms in algal thallus organization include palmella, dendroid, palmelloid, coccoid, filamentous, siphonaceous, heterotrichous, uniaxial, and multiaxial configurations. In colonial forms, individual cells maintain independence in both structure and function. The multicellular forms of algae can range from microscopic to macroscopic (Phaeophyceae and Rhodophyceae) groups growing to several meters in length. Multicellular forms have been derived by repeated divisions of unicellular forms. Colonial forms are developed by the aggregation of the products of cell division within a

mucilage mass. Filamentous forms are formed by repeated transverse divisions of cells without separation of daughter cells. Repeated nuclear divisions, without cross wall formation give rise to siphonaceous forms. Parenchymatous thalli are formed by the division of cells of a filament in two or more planes. These multicellular structures may be parenchymatous, and in some cases, the thallus exhibits differentiation. Their size ranges from one micron to several meters. On the basis of thallus organization, algae are divided into the following five groups:

(1) Unicellular forms

(2) Colonial forms

(3) Filamentous forms

(4) Siphonaceous forms

(5) Parenchymatous forms

1. Unicellular forms

Simple unicellular forms are found in all groups of algae except Charophyceae and Phaeophyceae. These forms are sometimes referred to as acellular since they function as complete living unit without any cellular differentiation. Unicellular forms can be classified into the following four sub-groups.

i. **Rhizopodial unicells:** These forms lack a rigid cell wall. They possess cytoplasmic projections which help them in amoeboid movement. In the absence of rigid cell wall, these forms are periplastic; e.g., Rhizochrysis (Chrysophyceae), Rhizochloris (Xanthophyceae), Chrysamoeba (Chrysophyceae) (Figure 8.2A).

ii. **Flagellated unicells:** Flagellated vegetative cells are found in all groups of algae except Cyanophyceae, Phaeophyceae and Rhodophyceae. They vary in the number and type of flagella. For example, in Chlorophyceae, vegetative cells, zoospores and gametes have two equal flagella. Their number may sometimes vary. In Dinophyceae and Xanthophyceae there are two unequal flagella; in the former they emerge in different planes and in the latter in the same plane. In Euglenophyceae there is only one flagellum, inserted at the anterior end. Flagellated unicells may be periplastic without cell wall (e.g., Euglena) or with a distinct cell wall (e.g Chlamydomonas). In Phacotus (Chlorophyceae), there is a thick calcareous covering (capsule) around the cell wall (Figure 8.2B-D).

iii. **Non-motile/Coccoid unicells:** These are non-motile coccoidal algae which do not possess flagella, eye spot, etc., meant for locomotion. The simplest non-motile forms are found in Cyanophyceae where they do not possess well organized nucleus and plastids (prokaryotic), e.g., Chroococcus. The non-motile unicells of Chlorophyceae possess nucleus and plastids (e.g., Chlorella; Figure 8.2E). The non-motile unicells of Bacillariophyceae, such as diatoms, are made up of two halves or theca, joined by a girdle band (Figure 8.3B).

iv. **Spiral filamentous unicells:** unicellular algae form spiral or coiled structures, e.g. Spirulina (Cyanophyceae; Figure 8.3A).

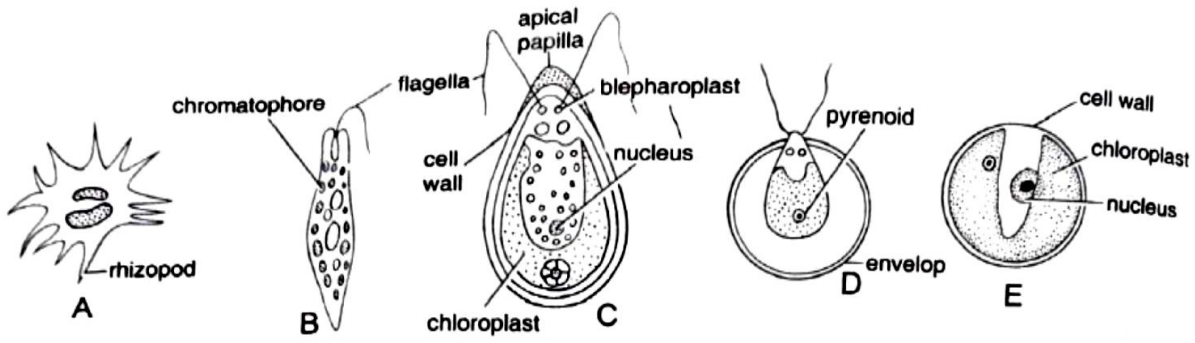

Figure-8.2 A-E: Unicellular algae: A. Chrysamoeba, B. Euglena, C. Chlamydomonas, D. Phacotus, E. Chlorella (H.D. Kumar, 1979)

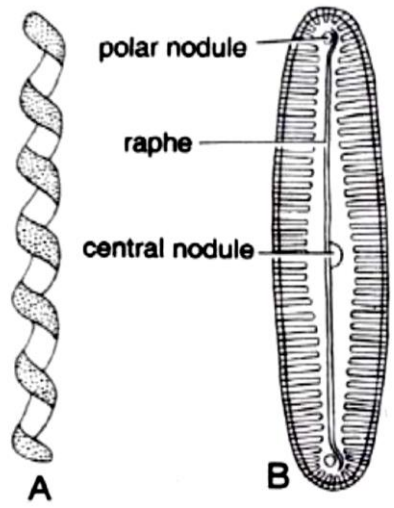

Figure-8.3 A-B. Unicellular algae: A. Spirulina, B. Pinnularia (H.D. Kumar, 1979)

(2) Colonial forms

The colonial habit is achieved by aggregation of the products of cell divisions within a mucilaginous mass, by aggregation of motile cells or juxtaposition of cells subsequent to cell divisions. Therefore, all members of a colony have similar structure. These associations are usually loose, and as such a colony may break into smaller pieces. In some colonial forms, all members of a colony are connected with each other by cytoplasmic connections; hence they cannot break into segments (e.g. Volvox). On the basis of morphology, colonial organization may be divided into the following four types:

i. **Coenobial:** A colony with a definite shape, size and arrangement of cells is known as coenobium. The number of cells in a coenobium is determined at the juvenile stage and subsequently there is only increase in size. Coenobia may be motile or non motile; in the former cells are flagellated (e.g., Pandorina, Eudorina, Volvox; Figure 8.4A-C) and in the latter without flagella (e.g, Hydrodictyon; Figure 8.4D).

ii. **Palmelloid:** In a palmelloid colony, unlike the coenobial forms, the number of cells, their shape and size is not definite. The cells remain irregularly aggregated within a common mucilagenous matrix, but they are independent and function as individuals In some palmelloid forms it is a temporary phase (e.g., Chlamydomonas), whereas in others it is a permanent feature as in Tetraspora (Chlorophyceae), Aphanotheca (Cyanophyceae; Figure 8.5A-B).

iii. **Dendroid:** Here the colony looks like a microscopic tree. As in palmelloid colony, the number, shape and size of the cells is also indefinite in dendroid colonies. A mucilagenous thread is present at the base of each cell, and the threads of different cells are united to form a branched structure. It gives a tree like appearance to the whole colony Chrysodendron (Figure 8.5C).

iv. **Rhizopodial:** In a rhizopodial colony the cells are united through rhizopodia (e.g., Chrysidiastrum Figure 8.5D).

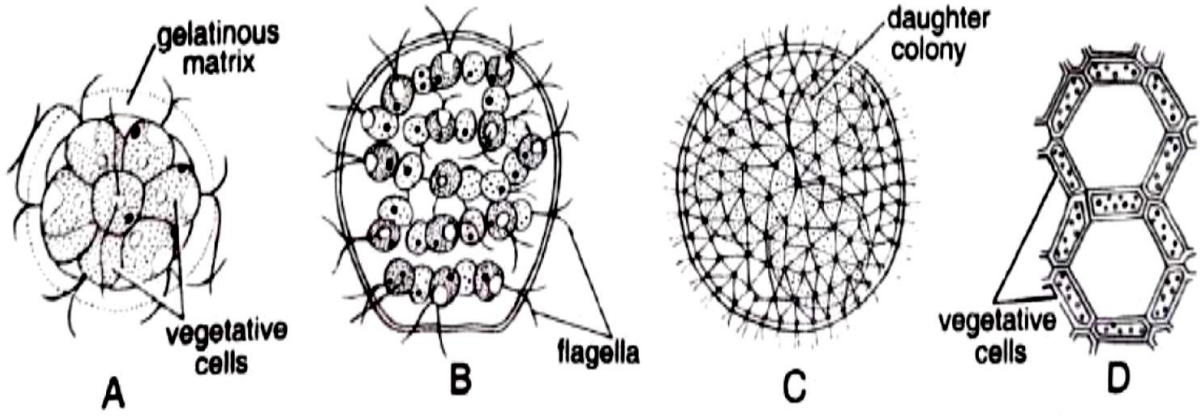

Figure-8.4 A. Pandorina, B. Eudorina, C. Vobvox, D. Hydrodictyon (H.D. Kumar, 1979)

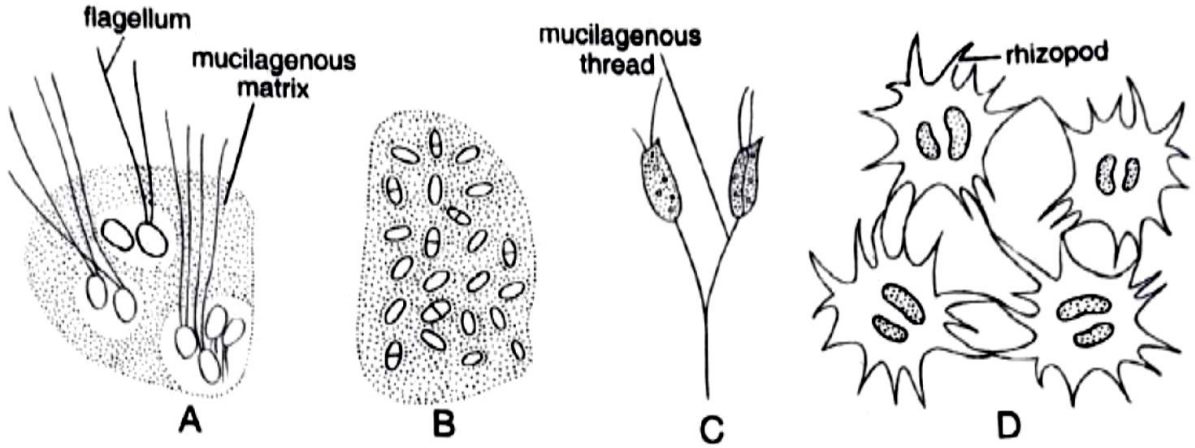

Figure-8.5 A. Tetraspora, B. Aphanotheca, C. Chrysodendron, D. Chrysidiastrum

(H.D.Kumar, 1979)

3. Filamentous forms

Filamentous forms are developed by repeated transverse divisions of cells. The daughter cells do not separate and they remain attached one upon the other in a definite sequence to form a filament. The filaments may be branched or unbranched, and the cells in a filament may be arranged in a single row (uniaxial) or more than one rows (multiaxial).

i. **Unbranched filaments:** Simple unbranched filaments are found only in a few groups of algae. Such filaments may be free floating (e.g. Spirogyra; Figure 8.6A) attached to some substratum e.g., Zygnema, Ulothrix, Oedogonium (Figure 8.6B-C) or form colony (e.g. Nostoc, Figure 8.7A-B).

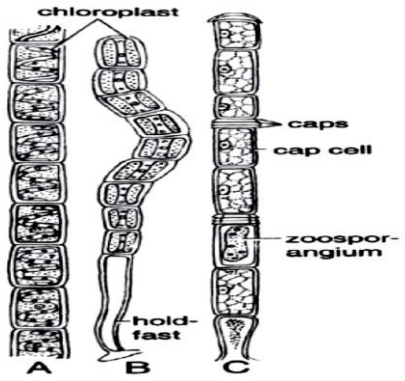

Figure-8.6: A-C. Filamentous algae: A. Spirogyra, B. Ulothrix, C. Oedogonium

(H.D. Kumar, 1979)

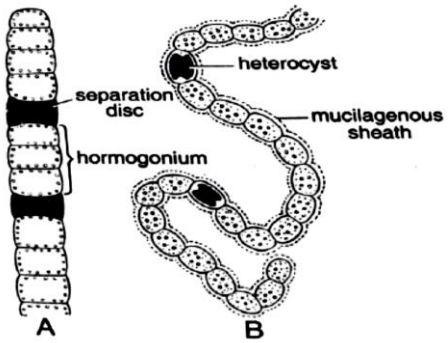

Figure-8.7A-B: Filamentous algae: A. Oscillatoria, B. Nostoc (H.D. Kumar, 1979)

ii. **Branched filaments:** Branched filaments are formed by repeated transverse divisions of lateral outgrowths of cells. The branching of filaments is may be falsely branched or truly branched.

Falsely Branched: The trichomes of blue greens may break either due to death or decay of the intercalary cells or at the point of heterocyst. The broken ends emerge out of the mucilaginous sheath in the form of a branch. They do not arise as lateral outgrowths e.g.,

Scytonema (Cyanophyceae; Figure 8.8A). False branches in Scytonema arise almost always in pairs at some distance from the heterocyst.

Truly Branched: When a cell in the filament occasionally starts division in a second plane, true branch is formed. Thus true branches arise as lateral outgrowths of the main filament. True branches are of the following three types: Simple filament, Heterotrichous habit, and Pseudoparenchymatous habit.

i. **Simple filaments:** Simple branched filaments remain attached to the substratum by a basal cell. In such filaments branches may arise from any cell except the basal cell. In Cladophora branches arise just below the septa between two adjacent cells (Figure 8.8B)
ii. **Heterotrichous:** In this type, the thallus is very much evolved and differentiated into prostrate and erect systems (e.g., Fritschiella, Ectocarpus, Drapamaldiopsis). Both the prostrate and the erect systems may be well developed (e.g., Fritschiella, Figure 8.8 C, F) or there is progressive elimination of prostrate (e.g. Draparnaldiopsis) or erect (e.g., Coleochaete) system (Figure 8.8 D, E).
iii. **Pseudoparenchymatous:** In many filamentous forms one or more central or axial filaments, together their branches, form a parenchymatous structure. If a pseudoparenchymatous thallus is formed by the branches of only one filament, it is called uniaxial (eg. Batrachospermum), and if branches of more than one filament are involved, it is said to be multiaxial (e.g. Polysiphonia: Figure 8.9 A-C).

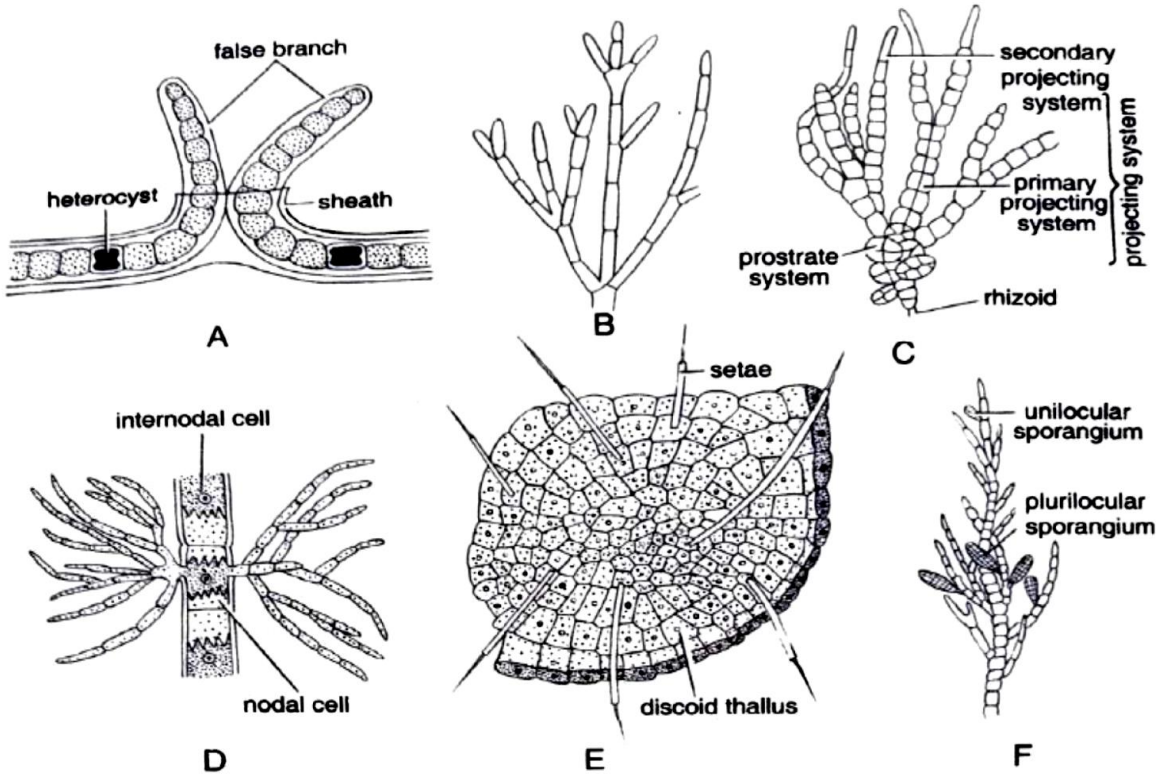

Figure-8.8 A-F: Branched filamentous algae: A. Scytonema (false branching), B. Cladophora (simplebranching), C. Fritschiella (heterotrichous), D. Drapamaldiopsis (heterotrichous), E. Coleochaete (heterotrichous), F. Ectocarpus (heterotrichous) (H.D. Kumar, 1979)

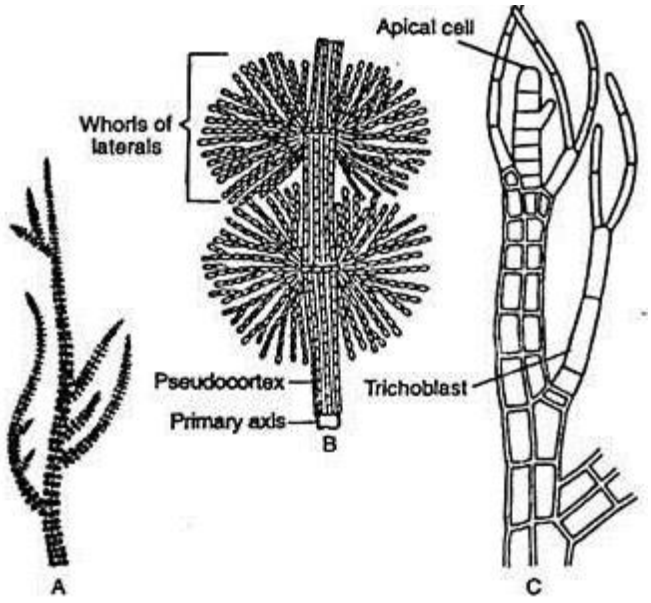

Figure-8.9 A-C: Pseudoparenchymatous habit: A. Batrachospermum B. Batrachospermum (portion of plant body) C. Polysiphonia (H.D. Kumar, 1979)

4. Siphonaceous forms: Here the thallus is made up of branched, aseptate, coenocytic, tubular filaments as the nuclear divisions accompanied by wall formation, eg. Vaucheria and Botrydium (Figure 8.10 A-B).

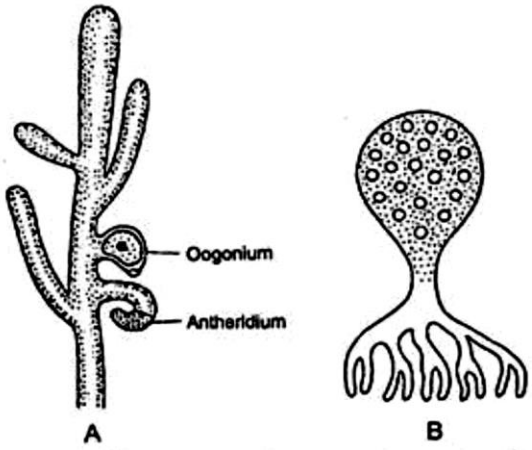

Figure-8.10 A-B: Siphonaceous algae A. Vaucheria B. Botrydium (H.D. Kumar, 1979)

5. Parenchymatous forms: In this type the flat foliose or tubular thalli are formed by the divisions of cells in two or more planes. The daughter cells do not separate from the parent and give rise to parenchymatous thalli of various shapes, like flat (Ulva; Figure 8.11A), tubular (Scytosiphon, Phaeophyceae) or complex (Sargassum: Figure 8.11B). The growth of such thalli is apical e.g. Fucus, Dictyota), intercalary (e.g. Laminara Figure 8.11C) or trichothallic (e.g., Porphyra, Rhodophyceae).

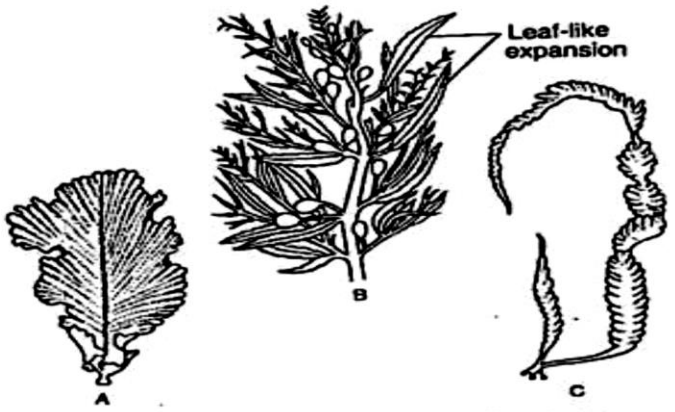

Fig. 3.9 : Parenchymatous algae : A. *Ulva*, B. *Sargassum*, and C. *Laminaria*

Figure-8.11: Parenchymatous algae: A. Ulva B. Sargassum C. Laminaria (H.D. Kumar, 1979)

8.4 ULTRASTRUCTURE OF ALGAL CELL

Cell Wall

Most of the members of algae consist of a cell wall which is composed of non-living material which is variously classified. In algae polysaccharides are chief constituent of cell wall with two major components (i) Fibrillar (Cellulose, Mannans, Xylans) and (ii) Amorphous (Alginic acid, fucoidan, galactans etc.). The fibrillar component forms the skeleton of cell wall and amorphous component forms the matrix embedding the fibrillar part. Different groups of algae have differential nature of cell wall as summarized in Table 8.1.

Table-8.1: Cell wall composition in different algae

Algal Group	Cell Wall Composition
Cyanobacteria (Blue-green algae)	Peptidoglycan, proteins, lipopolysaccharides
Chlorophyta (Green algae)	Cellulose, hemicellulose, pectins, glycoproteins
Charophyta (Stoneworts, Green algae relatives)	Cellulose, sporopollenin (in some species)
Phaeophyta (Brown algae)	Cellulose, alginates (alginic acid), sulfated fucans
Rhodophyta (Red algae)	Cellulose, agar, carrageenan, xylan, mannans
Chrysophyta (Golden algae)	Silica, cellulose, or absent in some species
Bacillariophyta (Diatoms)	Silica (forming frustules)
Euglenophyta (Euglenoids)	Proteinaceous pellicle (no rigid cell wall)
Dinophyta (Dinoflagellates)	Cellulose (in theca plates) or absent in some species

Plasma membrane: It is present just beneath the cell wall and it is lipoprotein bilayer made up of by lipids and proteins.

Cytoplasm: Inside the plasma membrane dense cytoplasm is present. In cytoplasm, membrane bound cell organelles such as mitochondria, chloroplasts, Golgi-bodies, endoplasmic reticulum and other eukaryotic cell organelles are present. Ribosomes are of 80s type. Cells of most algae contain one chloroplast per cell with the exception of few species whose cells have more than one chloroplast. Besides this, almost all chloroplasts bear one or more pyrenoids. The chloroplasts may be- cup-shaped, parietal, discoid, lobed, star shaped, spiral, and barrel or girdle shaped.

Nucleus: In eukaryotic algal cell, single nucleus is present in most of the algae, but multinucleate eukaryotic algal cell are also found in considerable number. True nucleus having nuclear membrane with nuclear pores is present in eukaryotic algal cell which is not different from the nucleus of higher plants. DNA is bounded with the histone proteins.

Flagella

Motile vegetative or reproductive cells are found in all groups of algae except Cyanophyceae and Rhodophyceae. Their motility is due to small filiform (thread like protoplasmic appendages called, flagella. The number of flagella varies from one to four to many (Oedogonium, Vaucheria) (Table 8.2). They are mainly of the following two types:

1. Whiplash or acronematic flagella: Such flagella have a smooth surface (Figure 8.12 A, B).

2. Tinsel or pleuronematic flagella: The surface of these flagella is covered with fine filamentous appendages, known as mastigonemes or flimmers (Figure 8.13A-D). They are further divided into three categories on the basis of arrangement of mastigonemes.

i. **Pantonematic:** In this type mastigonemes are arranged in two opposite rows or show radial arrangement.
ii. **Pantocronematic:** A pantonematic flagellum with a terminal fibril is known as pantocronematic.
iii. **Stichonematic:** Here mastigonemes develop only on one side of the flagellum. A motile cell may have either one or two types of flagella. It is a specific character. If all flagella of a cell are similar, it is known as isoknot and when dissimilar, it is called heteroknot. The motile stages of Chlorophyceae possess two or four anteriorly inserted whiplash flagella of equal length; whereas the members of Phaeophyceae and Xanthophyceae have one whiplash and one tinsel flagellum of unequal length.

A transection of flagellum reveals that it consists of nine peripheral doublet and two central singlet fibrils (Figure 8.14). All fibrils are enclosed within a common covering, formed by the extension of plasma membrane, but the two central fibrils have an additional covering of their own. The peripheral as well as central fibrils extend almost throughout the length of the flagellum. The nine peripheral fibrils at the proximal end are attached to a hollow basal body. The two central fibrils terminate just short to the diaphragm.

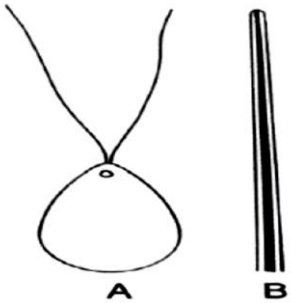

Figure-8.12 A-B: Acronematic flagella: A. An algal cell with acronematic flagella,

B. A single acronematic flagellum. (H.D. Kumar, 1979)

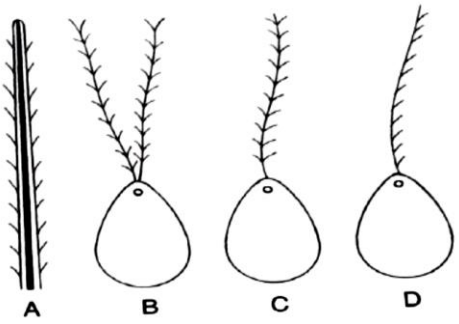

Figure-8.13A-D: Pleuronematic flagella: A. A pleuronematic flagellum showing mastigonemes,

B. A cell with two pantonematic flagella

C. A cell with pantocronematic flagellum

D. A cell with stichonematic flagellum (H.D. Kumar, 1979)

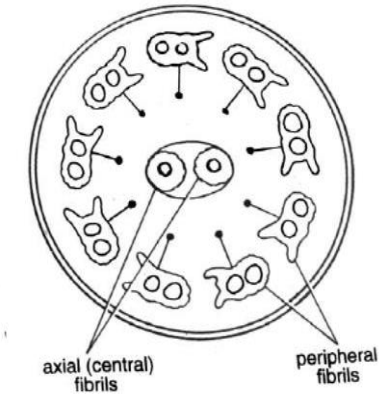

Figure-8.14: Cross section of a flagellum (H.D. Kumar, 1979)

Table-8.2: Nature and type of flagella in algae

Algal Group	Number and Type of Flagella	Characteristics
Cyanobacteria (Blue-green algae)	Absent	Movement via gliding or gas vesicles
Chlorophyta (Green algae)	2 or 4, equal, apical	Whiplash type, smooth (acronematic)
Charophyta (Stoneworts, Green algae relatives)	2, unequal	One whiplash, one tinsel type
Phaeophyta (Brown algae)	2, lateral	One whiplash, one tinsel type
Rhodophyta (Red algae)	Absent	Non-motile; lacks flagellated stages
Chrysophyta (Golden algae)	2, unequal	One whiplash, one tinsel; lateral insertion
Bacillariophyta (Diatoms)	Absent (except in some sperm cells)	Male gametes of centric diatoms have a single flagellum
Euglenophyta (Euglenoids)	1 or 2, anterior	One emergent, one reduced; both whiplash type
Dinophyta (Dinoflagellates)	2, perpendicular	One transverse (ribbon-like) and one longitudinal

Plastids and Photosynthetic pigments

The most prominent feature of an algal cell is the plastid, which makes an important characteristic of an algal cell for classification. Algal cells have a characteristic colour due to the presence of a combination of pigments, specific to each class. In all classes, except Cyanophyceae, these pigments are present within membrane bound organelles, known as plastids. In blue-green algae, the pigments are concentrated in cytoplasm, known as chromoplasm. Plastids which consist of chlorophyll a and chlorophyll b are called Chloroplasts and the one which lacks chlorophyll b are called Chromatophores. Based on this, the plastids are of two types, **1. Leucoplasts** (Colourless plastids) **2. Chromoplasts** (Coloured plastids). In algae, different forms and shapes of plastids are observed (Figure 8.15).

(i) Cup shaped: Chlamydomonas, Volvox

(ii) Discoid: Chara, Vaucheria, Dinophyceae, Bryopsidophyceae and many diatoms

(iii) Girdle or C shaped: Ulothrix

(iv) Ribbed: Volvocales

(v) Reticulate: Oedogonium, Hydrodictyon and Cladophora

(vi) Spiral or ribbon shaped: Spirogyra

(vii) Stellate: Zygnema

According to location the plastid may be categorized into **(i) Parietal:** Chaetophorales, Phaeophyta, Rhodophyta, Chrysophyceae, Pinnate Diatoms **(ii) Axial:** Porphyridium, Bangia.

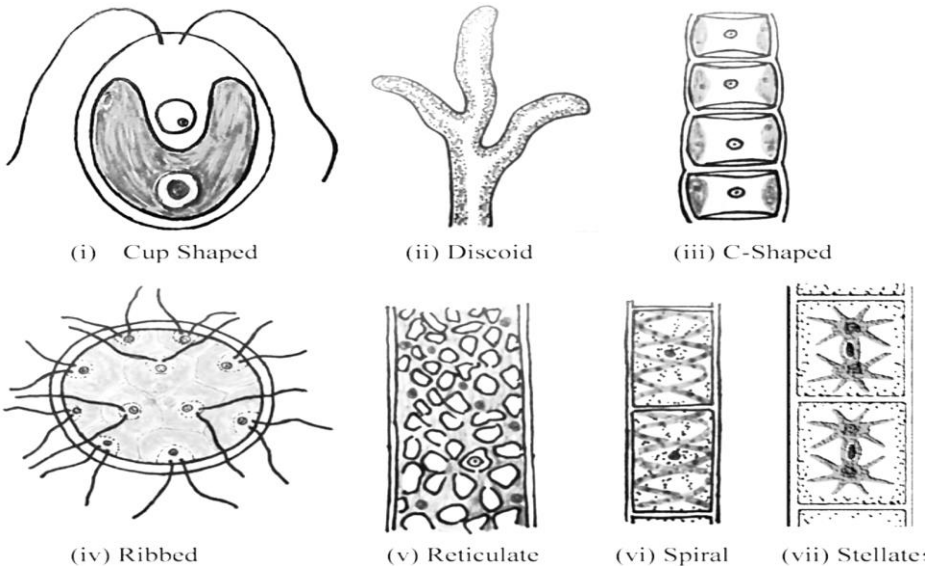

Figure-8.15: Various forms of plastids in algae (H.D. Kumar, 1979)

The basic structure of chloroplast is similar throughout the plant kingdom with an envelope, stroma and internal lamellar membranes. Only the Cyanophycean members show the typical prokaryotic structure, where the thylakoids are not bound in any envelope and they lie freely in cytoplasm. In general, the following types of photosynthetic pigments have been reported in an algal cell.

i. **Chlorophyll:** There are five types of chlorophylls, viz., chl a, b, c, d and e. Of these, chlorophyll a is present in all groups of chlorophyll algae, Euglenophyceae, chlorophyll c largely in algae of marine habitats (Phaeophyceae, Cryptophyceae, Bacillariophyceae and Chrysophyceae), chlorophyll d in some red algae only as a trace constituent and chlorophyll e in certain Xanthophyceae such as Vaucheria hamata and Tribonema bombycinum.

ii. **Xanthophyll:** More than 20 types of xanthophylls are known. They are formed by the incorporation of molecular oxygen into carotene molecule. Many xanthophylls, common in higher plants (lutein, violaxanthin, and neoxanthin), are found in the members of Chlorophyceae and Phaeophyceae. Fucoxanthin is the main xanthophylls pigment of Phaeophyceae and diatoms whereas myxoxanthophyll, myxoxanthin and oscilloxanthin are found only in Cyanophyceae.

iii. **Carotenes:** These are oxygen free alicyclic compounds, composed of isoprene units. There are five types of carotenes reported in different algal groups as listed in table, and it is an accessory photosynthetic pigment. The five types of carotenes occur in algae are: α–carotene in Chlorophyceae; Cryptophyceae and Rhodophyceae; β-carotene in all algal groups except Cryptophyceae, C- carotene in Chlorophyceae, E-carotene in Bacillariophyceae, Cryptophyceae, Phaeophyceae and Cyanophyceae and flavacene in members of Cyanophyceae.

iv. **Phycobilins:** These complexes of protein and bile pigments, present in the photosynthetic tissue of plants. There are six types of phycobilins in algae. Phycobilins are red (phycoerythrin) and blue (phycocyanin) pigments which are re confined to

Rhodophyceae and Cyanophyceae, respectively. They act as light harvesting pigments in photosynthesis and the light absorbed by them is transferred to chlorophyll a. Thus, like carotenoids, phycobilins are also accessory pigments.

Vacuoles

The vacuole in algae is a highly adaptable organelle that plays a crucial role in maintaining cellular homeostasis. Depending on the species and habitat, vacuoles can function in **storage, osmoregulation, buoyancy control, digestion, and detoxification**. The structural diversity of algal vacuoles reflects their adaptation to various environmental conditions. The vacuole in algae is a membrane-bound organelle with structural similarities to those in plant cells, but it varies in size, shape, and function depending on the type of algae and environmental conditions. The vacuole is enclosed by a single-layered membrane called the tonoplast. It regulates the movement of ions, water, and metabolites into and out of the vacuole. The tonoplast contains specialized transport proteins that maintain ion gradients. The vacuole contains water, ions, nutrients, pigments, waste products, and enzymes. The pH inside the vacuole varies based on its function (e.g., acidic in some cases for degradation). Some algae have pigment-containing vacuoles that store compounds like carotenoids.

Unicellular Algae: Typically have a **large central vacuole** that takes up most of the cell volume, similar to higher plants.

Multicellular Algae: May have multiple small vacuoles distributed throughout the cytoplasm. The size of the vacuole **can change** in response to environmental factors like water availability.

Specialized Vacuoles in Different Algae

i. **Contractile Vacuoles (Osmoregulation):** Found in freshwater algae (e.g., Chlamydomonas). Help expel excess water to prevent the cell from bursting due to osmotic pressure. Work by illing with water and then contracting to release it outside the cell.
ii. **Gas Vacuoles (Buoyancy Control):** Found in cyanobacteria (blue-green algae) and some planktonic algae. Composed of gas-filled vesicles that help regulate buoyancy. Allow algae to adjust their position in the water column for optimal light absorption.
iii. **Lytic Vacuoles (Degradation and Recycling):** Contain hydrolytic enzymes for the breakdown of cellular waste and damaged organelles. Function similar to lysosomes in animal cells.
iv. **Storage Vacuoles:** Store starch, lipids, or other energy reserves in some algae. Important for survival in nutrient-limited environments.

Reserve food material

Polysaccharides and fats are two principle storage products in different members of Algae. The reserve food material of algae varies depending on the type of algae. Pyrenoids are proteinaceous bodies present in chromatophores. These organelles are considered to be associated with the synthesis and storage of starch. In members of Chlorophyceae, pyrenoids are surrounded by starch plates. But in some algae such as diatoms, they accumulate lipids instead of starch. Here, some key reserve food materials found in different groups of algae are listed (Table 8.3).

Table-8.3 Reserve food material found in different algae

Algal Group	Reserve Food Material	Examples
Chlorophyceae (Green Algae)	Starch (similar to plant starch)	Chlamydomonas, Spirogyra, Ulva
Phaeophyceae (Brown Algae)	Laminarin, Mannitol	Laminaria, Fucus, Sargassum
Rhodophyceae (Red Algae)	Floridean Starch (similar to glycogen)	Polysiphonia, Gelidium, Porphyra
Bacillariophyceae (Diatoms)	Chrysolaminarin, Lipids	Navicula, Cyclotella
Euglenophyceae (Euglenoids)	Paramylon (a β-1,3-glucan)	Euglena
Xanthophyceae (Yellow-green Algae)	Oil, Starch	Vaucheria
Cryptophyceae	Starch-like polysaccharides	Cryptomonas
Dinophyceae (Dinoflagellates)	Starch, Oil	Ceratium, Noctiluca

8.5 SUMMARY

Algae are a diverse group of photosynthetic organisms primarily classified within the kingdom Protista, though some, like cyanobacteria (blue-green algae), are prokaryotic bacteria. They inhabit varied environments, including aquatic ecosystems (freshwater and marine), moist soil, and extreme habitats like ice or hot springs. Ranging from unicellular forms (e.g., Chlamydomonas) to multicellular giants (e.g., kelp), algae lack true roots, stems, and leaves, distinguishing them from terrestrial plants. Algae exhibit diverse structures, from single cells to complex filaments (e.g., Spirogyra) and parenchymatous forms. Their cell walls may contain cellulose, silica (diatoms), or be absent. Photosynthetic pigments vary—chlorophyll-a is universal, supplemented by accessory pigments like phycobilins (red algae) and fucoxanthin (brown algae), determining their color and classification into groups such as Chlorophyta (green), Rhodophyta (red), and Phaeophyta (brown). Algae reproduce both asexually (via binary fission, spores, fragmentation) and sexually (through gamete fusion). Some exhibit complex life cycles with alternation of generations (e.g., Ulva).

8.6 TECHNICAL TERMS

Thallus, Pigment, Thallophyte, Colonial, Unicellular

8.7 SELF ASSESSMENT QUESTIONS

Q.1 Give a brief general account on algae.

Q.2 Describe the various aquatic algae.

Q.3 Write a detailed account on algae of unusual habitats.

Q.4 Explain the various reserve food materials of algae.

Q.5 Describe the thallus organization in algae.

Q.6 Describe the ultra structure of algal cell.

8.8 SUGGESTED READINGS

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Dr. K. Babu

LESSON – 9

NUTRITION AND REPRODUCTION IN ALGAE

OBJECTIVE OF THE LESSON

Students are able to know the various nutritional types and modes of reproduction in algae under both unfavorable and favourable conditions.

STRUCTURE OF THE LESSON

9.1 INTRODUCTION

From the view point of their nutrition the algae are autotrophic. They synthesize their food from inorganic materials such as carbon dioxide, water and minerals by means of photosynthesis. Chlorophyll is the most common pigment in all the algae. Sometimes, the green colour of the plastids is masked by other pigments, such as, fucoxanthin a yellow pigment which dominates in brown algae. Phycoerythrin and phycocyanin pigments are found in red and blue green algae respectively. The aquatic species of algae obtain water and carbon dioxide by osmosis and diffusion processes respectively from the water in which they grow. The algae, like other chlorophyllous plants, require C, H, O, P, K, N, S, Ca, Fe and Mg and also traces of Mn, Bo, Zn, Cu and Co. For certain algae, additional elements are required such as Si for diatoms and Mo for *Scenedesmus*. The algae also synthesize oil and proteins from the carbohydrates which they manufacture and soluble forms of nitrogen and other minerals available in solution in the water in which they are found.

9.2 MODES OF NUTRITION IN ALGAE

i. **Osmotrophy**: It is a common form of feeding mechanism in algae living in aquatic habitats. Organisms undergoing osmotrophy obtain nutrition by the movement of dissolved organic compounds from the water via osmosis. Aquatic algae-like *Zygnema*, *Vaucheria*, and *Cladophora* etc., generally undergo osmotrophy to make food.

ii. **Photoautotrophy**: It is also called "light eating". Organisms undergoing photoautotrophy obtain nutrition by the light energy (sunlight) and inorganic sources like atmospheric CO_2

and H_2O to prepare their food. Aerial algae-like *Phyllosiphon*, *Trentipohlia*, *Chaetophora* and *Scytonema* etc., undergo photoautotrophy.

iii. **Heterotrophy**: Algae follow heterotrophic strategies to acquire nutrients from organic carbon and nitrogen sources such as carbohydrates, proteins and fats.

iv. **Phagotrophy**: It is another type of feeding mechanism found in algae. Organisms undergoing phagotrophy obtain nutrition by engulfing large food particulates from the cell surrounding through phagocytosis or food internalization. Dinoflagellates, Diatoms, and Euglenoids etc., undergo phagotrophy.

v. **Mixotrophy:** Now it is widely accepted that algae use a complex spectrum of nutritional strategies, combining photoautotrophy and heterotrophy, which is referred to as mixotrophy. Some mixotrophs are mainly photosynthetic and only occasionally use an organic energy source. Some algal forms require certain growth factors like vitamins, essential amino acids and fatty acids for their growth.

Other feeding mechanisms in algae

The others may show some different feeding mechanisms, based on which algae are classified into the following major types:

i. **Obligate phototrophs**: Algae belonging to this group primarily obtain nutrition via utilizing inorganic sources like CO_2, H_2O and sunlight or through photosynthesis. In case of limited sunlight, obligate phototrophic algae sustain life through phagotrophy or osmotrophy. E.g. *Dinobryon divergons*, *Heterokontophyta*, etc.

ii. **Obligate heterotrophs**: Algae belonging to this group primarily obtain nutrition by a heterotrophic mode. In conditions of limited heterotrophy, they sustain themselves by undergoing phototrophy. E.g. *Dinophyta*, *Gymnodium gracilentum*, etc.

iii. **Facultative mixotrophs**: Algae belonging to this group obtain nutrition through photoautotrophy as well as heterotrophy. Example: *Dinophyta*

iv. **Obligate mixotrophs**: Algae belonging to this group primarily obtain nutrition through photoautotrophy and need B-complex vitamins, amino acids, and fatty acids for growth. Examples: *Euglena gracilis*, *Euglenophyta*, etc.

Classification of Algae on the basis of nutritional strategies

a) Obligate heterotrophic algae: These algae which do not synthesize their protoplasm solely from inorganic sources but require some of the essential elements, usually carbon and nitrogen. **E.g. *Gymnodium, Grecilentum,***

b) Facultative heterotrophic algae: These are primarily heterotrophic but are capable of sustaining themselves by phototrophy when prey concentrations limit their growth. E.g. *Dinophyta*

c) Facultative phototrophic algae: The primary mode of these algae are phototrophy, but they can be supplement growth by phagotrophy /or osmotrophy when light is limiting. E.g. *Dinobryon*

d) Obligate photoautotrophic algae: The algae which grow in an entirely inorganic medium in the presence of light are known as photoautotrophic. In other words, using light energy they synthesize their protoplasm from exclusively inorganic sources. E.g. Members of green algae, Cyanobacteria

e) Facultative mixotrophic algae: These can grow equally well as phototrophs and heterotrophs. E.g. *Fragilidium*

f) Obligate mixotrophic algae: These are also known as photoauxotrophic algae. These algae require in addition certain vitamins, usually B-12, thiamine or biotin for their growth. Several algae (e.g., species of *Ocaromonas*) digest solid particles of food and are known as phagotrophic. E.g. *Euglena*, *Euglenophyta*

g) Parasitic Algae: Parasitic Algae are grown parasitically on various plants and animals. E.g. *Cepheleuros* parasitic on Mango, Tea, Coffee, pepper and Rhododendron leaves.

9.3 REPRODUCTION IN ALGAE

Algae reproduce both asexually as well as sexually. The asexual method of reproduction includes reproduction by vegetative methods and reproduction by spores. The Vegetative mode of reproduction is known in primitive algae whereas; in higher forms both asexual and sexual reproductions are common. The different methods of reproduction in algae are discussed below (Figure 9.1).

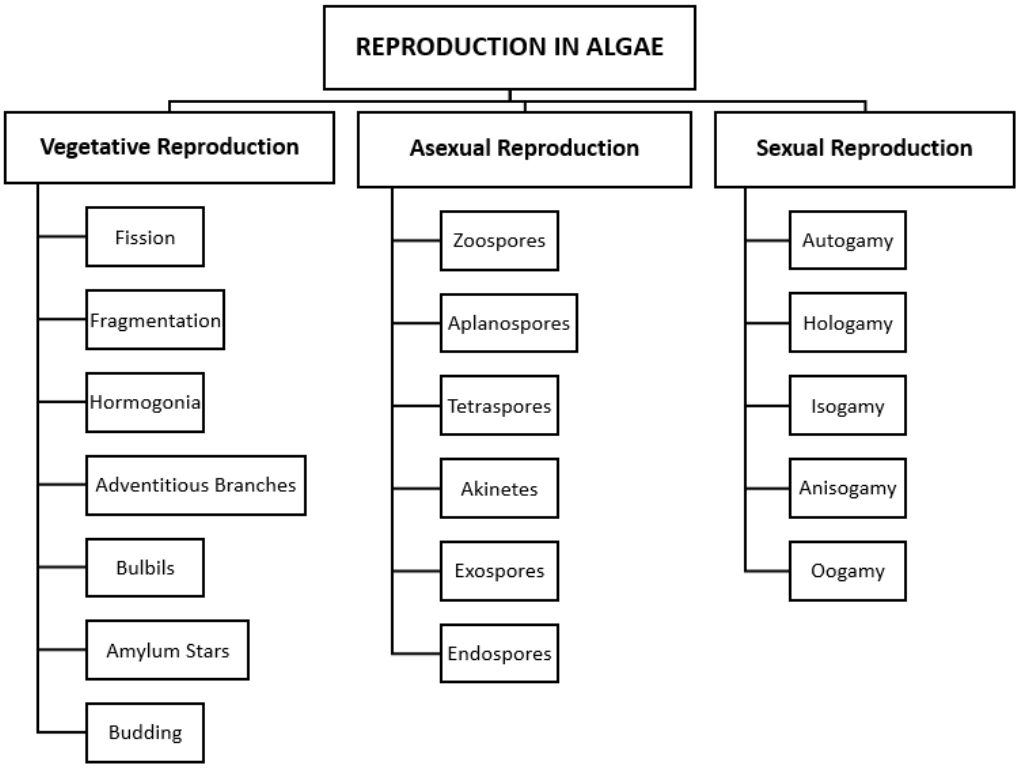

Figure-9.1: Various types of reproduction algae

Vegetative reproduction

The vegetative reproduction includes all those processes of propagation in which portions of the plant body become separated off to give rise to new individuals without any obvious changes in the protoplast or in other words, it does not involve rejuvenation of the protoplasts. It is the most common method of reproduction in algae and takes place by the following means:

1. Cell division or fission: It is the simplest method of propagation and is commonly found in unicellular algae (e.g., *Euglena*, *Chlamydomonas*), desmids and diatoms. In this process, the unicellular algal cell divides mitotically to form two daughter cells, each eventually grows into an independent organism (Figure 9.2).

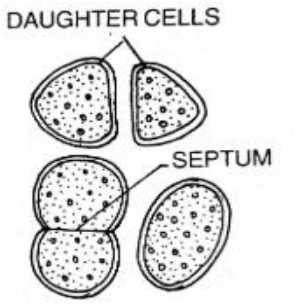

Figure-9.2: Cell division (https://tinyurl.com/5cbwyp7v)

2. Fragmentation: In filamentous forms like *Ulothrix*, *Oedogonium*, *Spirogyra* and *Zygnema* the thallus often breaks into small fragments. Each fragment has the capability to grow independently and forms a new thallus. The fragmentation of filaments may be due to mechanical pressure, dissolution of transverse walls or difference in turgor pressure between adjoining cells. In colonial blue green algae, vegetative propagation takes place by fragmentation of larger colonies (Figure 9.3).

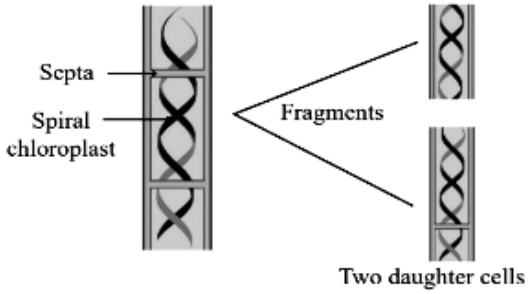

Figure-9.3: Fragmentation (https://tinyurl.com/5ejnjbpx)

3. Hormogonia: It is a characteristic method of reproduction in blue-green algae. unfavourable conditions the trichome breaks into motile segments of varying length, called hormogonia. The fragmentation of parent filament into hormogonia may be due to the formation of intercalary heterocysts, specialized separation discs or necridia or due to death and decay of intercalary cells of the trichome (Figure 9.4). Hormogonia are commonly found in *Nostoc*, *Oscillatoria* and *Cylindrospermum*.

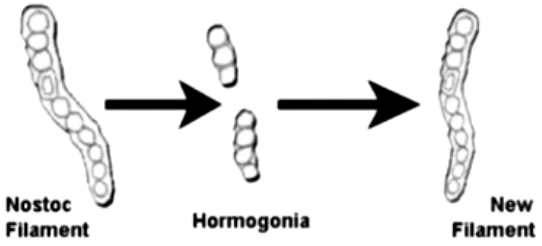

Figure-9.4: Hormogonia (https://tinyurl.com/ysu5xts8)

4. Formation of adventitious branches: Adventitious branches are formed in some large thalloid forms of algae. These branches, when get detached from the parent thallus, develop into new plants (Figure 9.5; e.g., *Dictyota*, *Fucus*). Adventitious branches like protonema, formed on the internodes of *Chara* or stolon of Cladophora glomerata, are found.

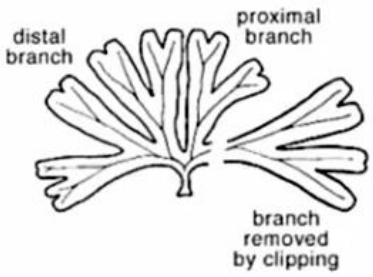

Figure-9.5: Adventious branches (https://tinyurl.com/4mwp8scj)

5. Tubers: On the rhizoids and the lower nodes of *Chara* some tuber like structures are formed due to storage of food material. When detached from the parent plant, the tuber produces an independent plant (Figure 9.6). Similar structures are also found in *Cladophora*.

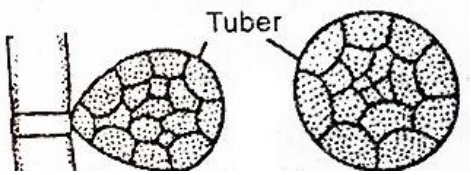

Figure-9.6: Tuber (https://tinyurl.com/538ejc3c)

6. Budding: In some algae (e.g., *Protosiphon*) vegetative propagation takes place by budding. Bud like structures are formed due to proliferation of vesicles. They eventually get separated from the parent plant by the formation of the septum, and have the capacity to form plants (Figure 9.7).

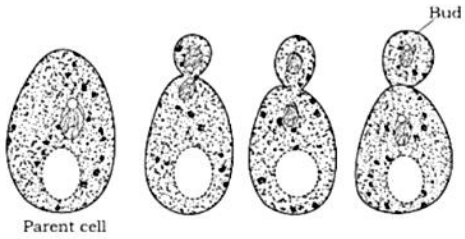

Figure-9.7: Budding (https://tinyurl.com/mr2x6pbv)

7. Bulbils: Tuber-like outgrowths are developed due to storage of food at the tip of rhizoids and on the lower nodes of *Chara*, called bulbils (Figure 9.8). After detachment from the plant body, bulbils grow into new plants.

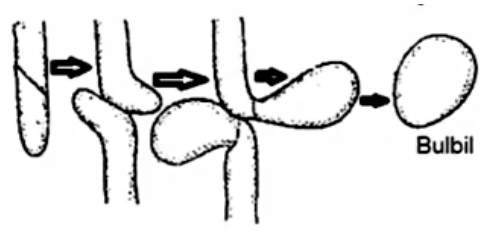

Figure-9.8: Bulbil (https://tinyurl.com/538ejc3c)

8. Amylum stars: Star-shaped aggregation of starch containing cells develops on the lower nodes of *Chara*. These structures are called amylum stars (Figure 9.9). When detached from the plant body, they grow into new plants.

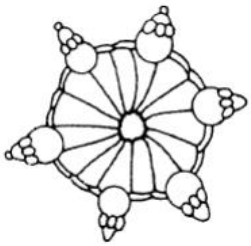

Figure-9.9: Amylum stars (https://tinyurl.com/mw5u5h7d)

9. Hormospores or hormocysts: Hormospores are thick walled hormogones which are produced in drier conditions (Figure 9.10).

Figure-9.10: Homospores (https://tinyurl.com/37nsna2h)

10. Protonema: Secondary protonema develops either from the rhizoidal node of primary protonema or from the basal node of primary rhizoid. Secondary protonema develops into new plant just like primary protonema (Figure 9.11 *Chara*).

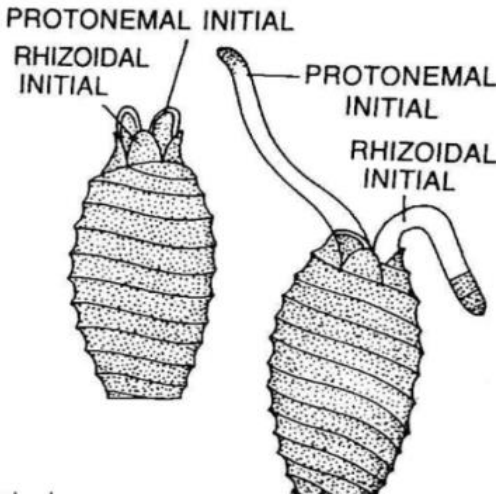

Figure-9.11: Protonema (https://tinyurl.com/muddx976)

Asexual reproduction

In a large number of algae asexual reproductions takes place with the help of different kind of spores and other structures. Basically, spores are meant for asexual reproduction and each spore can grow into a new thallus. Spores are one celled structure and are produced internally in the case of algae. They are produced within the vegetative cell (*Chlamydomonas*) or in a specialized structure called sporangia. They may be motile or non-motile. Motile spores are called zoospores and non-motile as aplanospores.

1. Zoospores: These are flagellated asexual spores which are formed in zoosporangium or directly from the vegetative cells (Figure 9.12A). The zoospores may be bi, quadric or multiflagellate. The multiflagellate zoospores are of again two types 1. Flagella arranged on entire length of body 2. Arranged in a ring surrounding a beak like projection. e.g., *Chlamydomonas* (biflagellate), *Ulothrix, Cladophora* (quadriflagellate), *Vaucheria, Oedogonium* (multiflagellate). In *Pediastrum*, the zoospores do not germinate or divide but orientate themselves in a single plane and become opposed to form a colony just like the parent cell. But the multinucleate and multiflagellate zoospores as found in *Vaucheria* (Figure 9.12B) are called synzoospores. Each zoospore has a chloroplast and an eye spot. The zoospores may be either haploid or diploid. They are formed within the zoosporangium. There may be single zoospore (e.g., *Oedogonium*) or many zoospores (e.g., *Cladophora*) per zoosporangium. Zoospores are either haploid or diploid depending on the nature of plant body, gametophytic or sporophytic on which it develops. The zoospores are liberated either by the disintegration of the zoosporangial wall or by the formation of an apical pore on the zoosporangium. After liberation the zoospores swim for a while, then withdraw their flagella, encyst and ultimately germinate into new plants.

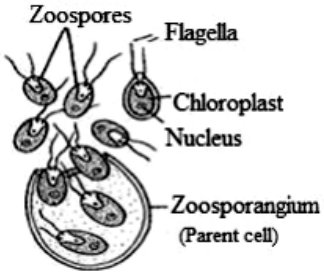

Figure-9.12: A. Zoospores B.Synzoospores

(https://tinyurl.com/mr3h63cf) (https://tinyurl.com/mry24dft)

2. Aplanospores: These are non-motile spores, commonly found in terrestrial algae, but some aquatic algae (e.g., *Ulothrix*, *Microspora*) also form them during drought conditions. They differ from zoospores in having a distinct wall and in the absence of flagella. Each cell may form a single aplanospore or its protoplast may divide to form many aplanospores (Figure 9.13).

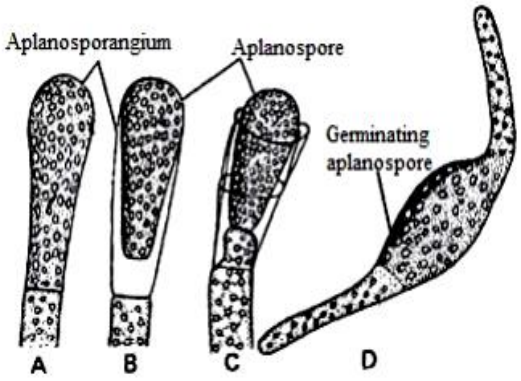

Figure-9.13: Aplanospores (https://tinyurl.com/stud6udm)

3. Hypnospores: Aplanospores of some algae like *Pediastrum* and *Sphaerella* secrete thick walls to overcome prolonged period of desiccation. Such thick walled aplanospores are called hypnospores (Figure 9.14). Under favourable conditions, hypnospores germinate and grow into new individuals or their protoplast with the parent wall. They are found in many blue-green and green algae.

Figure-9.14: Hypnospores (https://tinyurl.com/yckxc88c)

4. Tetraspores: Diploid plants of some algae (e.g., *Polysiphonia*) form non-motile spores which are called tetraspores (Figure 9.15). They are formed within tetrasporangium, usually by meiosis, and are haploid. They gernminate to fom haploid plants.

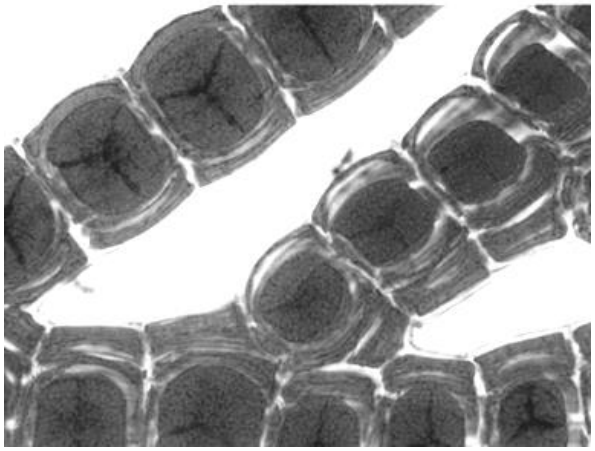

Figure-9.15: Tetraspopres (https://tinyurl.com/4e6bjuby)

5. Autospores: structure similar to the parent cell is called autospores. In *Scenedesmus* and many members of the order Chlorococcales (e.g. *Chlorella*) the aplanospores acquire all distinctive features of the parent cell before their sporangium. The so formed autospores are infact replica of the parent cell, the only difference is that they are smaller in size (Figure 9.16).

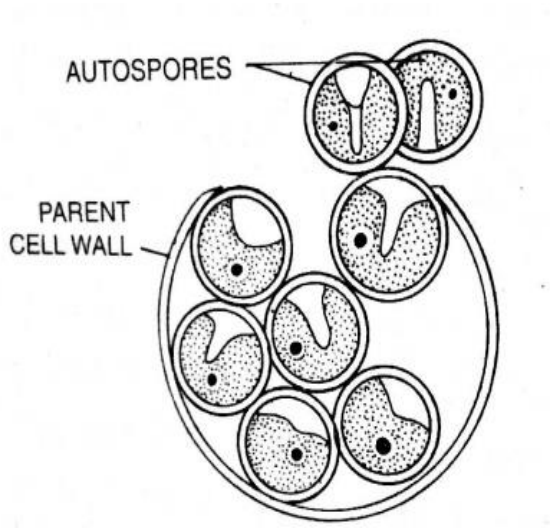

Figure-9.16: Autospores (https://tinyurl.com/mupsz9us)

6. Akinetes: In some algae, vegetative cells develop into thick walled spore like structures with abundant food reserves which are called as akinetes (Figure 9.17). Unlike the aplanospores, akinetes will have additional wall layers around the protoplast which are fused with the parent wall. They are resistant to unfavourable environmental conditions. The formation of akinetes, besides other factors, is affected by the availability of carbohydrates and light. They are found in many blue-green and green algae.

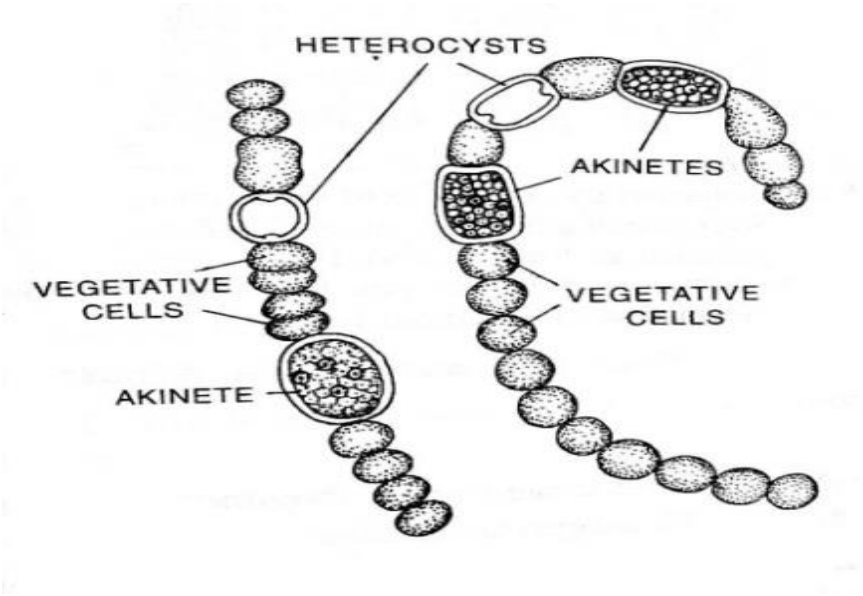

Figure-9.17: Akinetes (https://tinyurl.com/4z4n4ryu)

7. Bispores: When two spores are formed in a sporangium they are called bispores and the sporangium is termed as bisporangium (Figure 9.18). E.g. *Grateloupia filicina, Porphyra* and *Lithophylum littorale*.

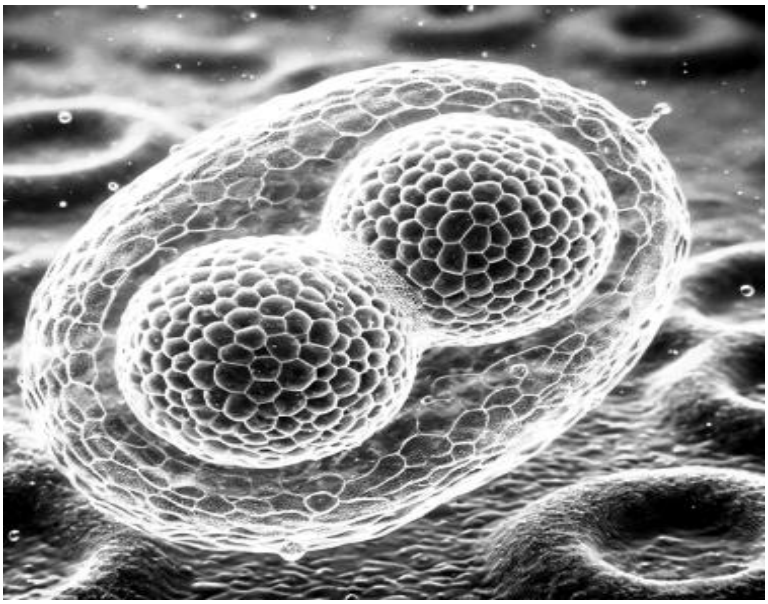

Figure-9.18: Bispore (https://tinyurl.com/2u5mv4vj)

8. Carpospores: These are formed in carposporangium during triphasic life cycle of Rhodophycean members (Figure 9.19). They are formed from zygote and are diploid in nature. Example: *Polysiphonia* , *Gracilaria* , and *Grateloupia*.

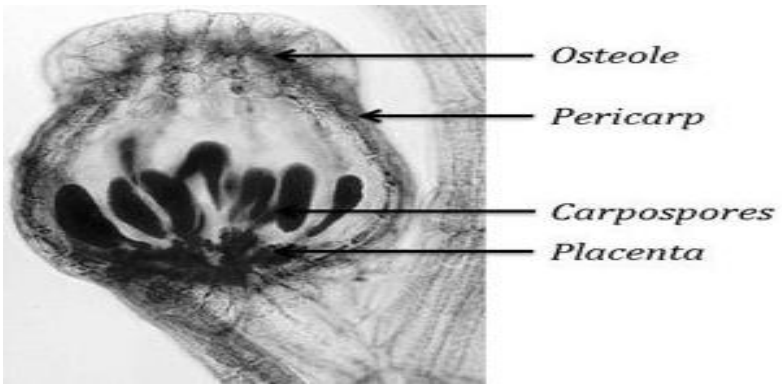

Figure-9.19: Carpospores (https://tinyurl.com/chnvt3xc)

9. Endospores: These are formed in the sporangium by successive repeated divisions of cell contents. All spores are formed first, and then the sporangium opens to liberate the motile spores (Figure 9.20). e.g. *Dermocarpa clavata.*

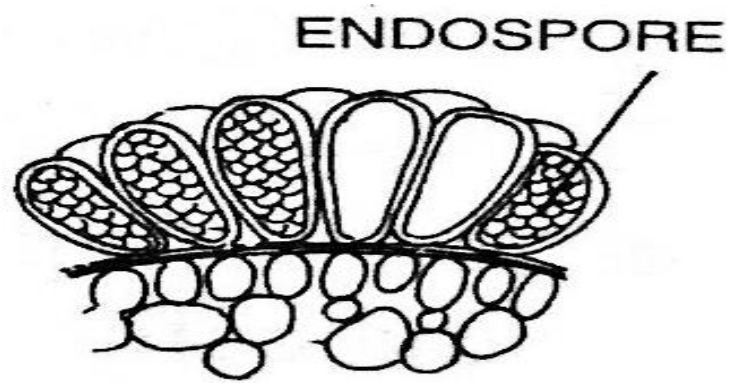

Figure-9.20: Endospores (https://tinyurl.com/m39umhk3)

10. Exospores: During exospore formation in Cyanophycean members, the sporangium gets burst at the apex and is exposed to the external environment and further by successive repeated divisions of cell contents the spherical spores are formed which are termed exospores (Figure 9.21). All spores get liberated one by one. eg. *Chamaesiphon, Stichosiphon*.

Figure-9.21: Exospores (https://tinyurl.com/ykkm9xeu)

11. Monospores: Single spores formed in a sporangium are termed as monospores. Commonly monospores are found in Brown and Red algae and are considered to be the commonest asexual spores of red algae.

12. Neutral Spores: These are common in red algae for example *Bangia* where, the vegetative cells directly get transformed into spores and such spores are termed neutral spores.

13. Paraspores: When more than four spores are formed because of reduction division in a sporangium in red algae, such spores are called as paraspores or polyspores. E.g. *Palmaria elegans* , *Ceramium* sp.

14. Statopsores: Thick and ornamented smooth walled spores of bacillariophyceae are termed as Statospores. E.g. *Chaetoceros* (Bacillariophyceae), Chrysophyceae and Xanthophyceae members.

15. Heterocysts: According to some phycologists, heterocysts are sometimes able to reproduce asexually. These structures are found in blue green algae and depending upon the position in thallus they may be terminal or interstitial (Figure 9.22).

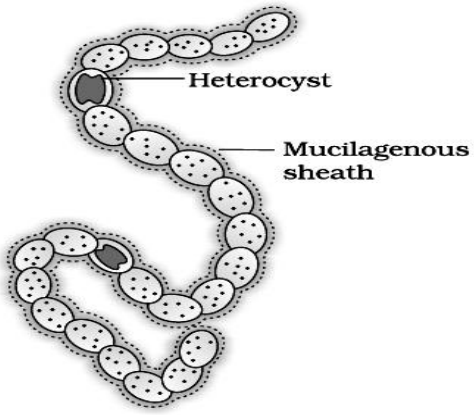

Figure-9.22: Heterocysts (https://tinyurl.com/5n6svsp9)

16. Auxospores: auxospores are produced in the members of Bacillariophyceae.

17. Nannocytes: In the members of chroococcales, the cell content divides repeatedly to produce numerous very small spores (Figure 9.23). E.g., *Macrocystis, Gloeocapsa.*

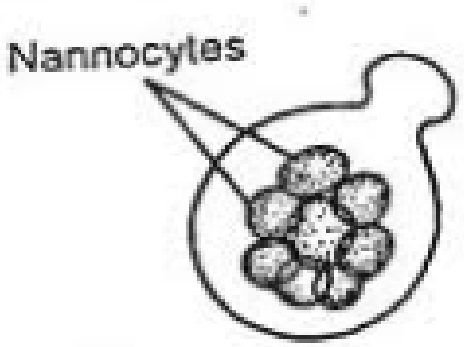

Figure-9.23: Nannocytes (https://tinyurl.com/3yhsy8r8)

18. Gongrosira stage of *Vaucheria:* In *Vaucheria*, the protoplast divides into several cysts like structures or hypnospores. This stage looks like an algal form '*Gongrosira'*. Each hypnospore or cyst may give rise to new thallus.

19. **Cysts:** Cysts are the resting spores of many algae. During dry season, the protoplast divides into many small units. Each daughter protoplast secretes a wall around it to form a cyst. When favourable season comes, the cysts germinate into new thalli. E.g. *Protosiphon*, *Vaucheria*, *Botrydium*, *Acetabularia*.

Sexual reproduction

All groups of algae, except Cyanophyceae, reproduce sexually when gametes fuse to form zygote. In contrast to vegetative and asexual reproduction, it leads to the creation of new combinations of genes by pooling together in one line of descent, the genes derived from the different parents, thus resulting in a reshuffling of the gene material. On the basis of the structure and physiological behavior of sex organs and their complexity, the following six types of sexual reproduction are recognized in different groups of algae.

1. Autogamy: When two gametes of the same mother cell fuse to form a diploid nucleus, it is called autogamy. In this process there is only karyogamy (fusion of two gametic nuclei). The autogamy lacks incorporation of external genes. Hence, plants developing as a result of autogamy do not show new characters. Diatoms are the common example of autogamy.

2. Hologamy: In *Chlamydomonas* and *Dunaliella*, the vegetative cells of different strains (+) and (-) behave as gametes and fuse to form zygote (Figure 9.24).

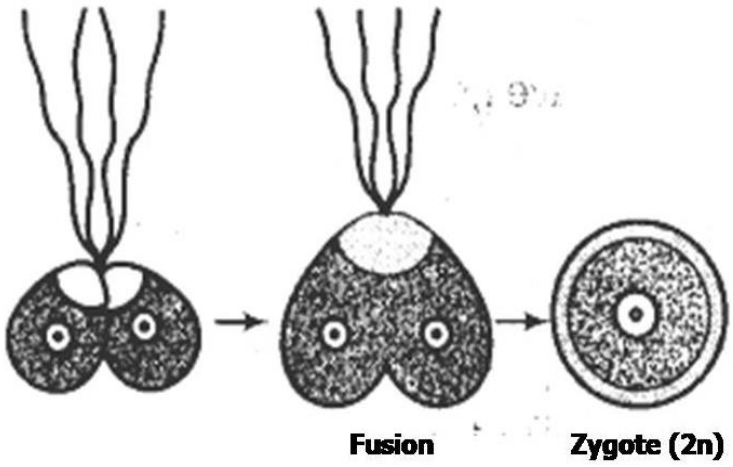

Figure-9.24: Hologamy in algae (https://tinyurl.com/bdfxvsek)

3. Isogamy: In isogamy the two gametes which fuses to form zygote, are morphologically and physiologically similar (Figure 9.25). Such gametes are called isogametes, as they are indistinguishable into plus and minus strains. They are usually motile and flagellate. Isogametes are found in *Ulothrix*, *Chlamydomonas eugametos*, etc.

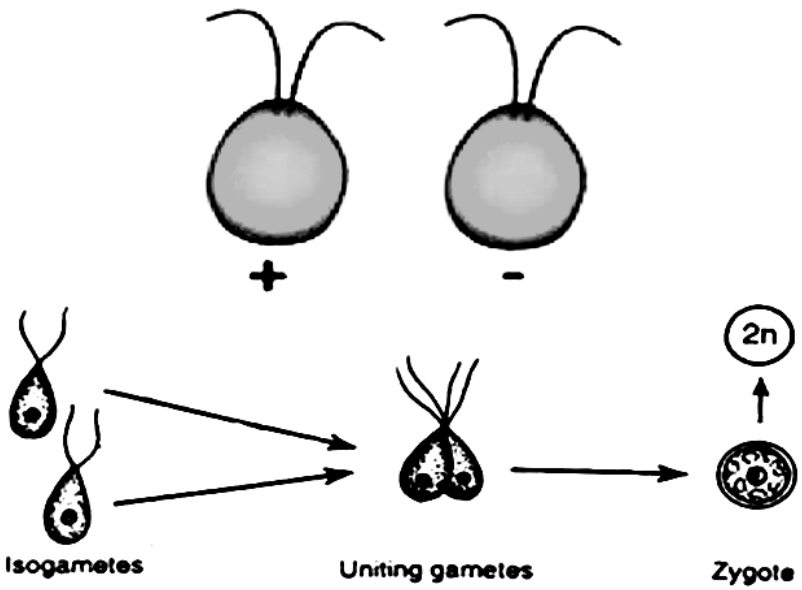

Figure-9.25: Isogamy in algae (https://tinyurl.com/vn5czt6s)

4. Physiological anisogamy: In some algae like *Spirogyra*, *Zygnema* and *Ectocarpus*, though gametes are similar in morphological characters, they show physiological variation with plus (+) and minus (-) strains.

5. Anisogamy: In anisogamy, fusion takes place between morphologically and physiologically distinct gametes (anisogametes) (Figure 9.26). The male or microgametes are smaller and more active, whereas the female or macrogametes are larger and sluggish. *Chlamyadomonas braunii* and *Pandorina* are the common examples for anisogamy.

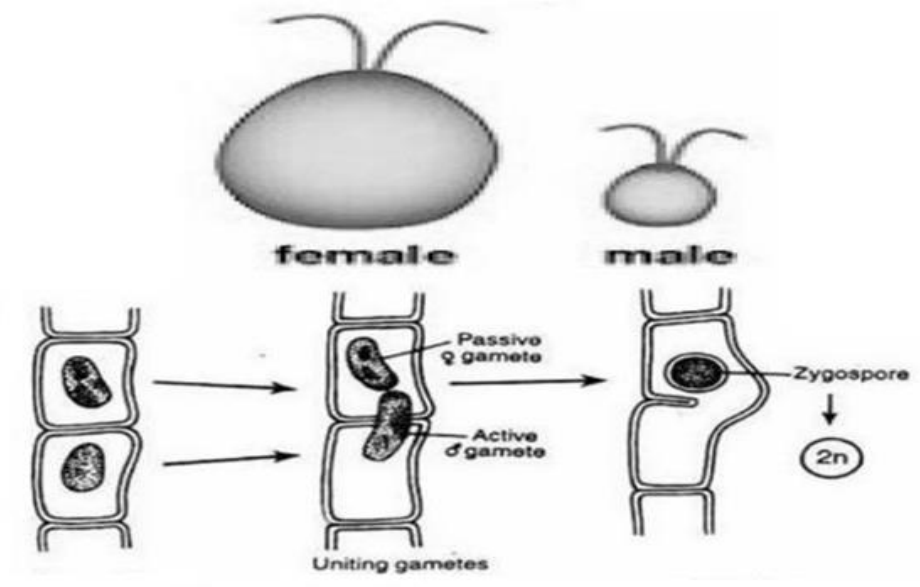

Figure-9.26: Anisogamy in algae (https://tinyurl.com/vn5czt6s)

6. Oogamy: This is the most advanced type of sexual reproduction. In this process a large nonmotile egg or ovum fuses with a small motile sperm or antherozoid (Figure 9.27). Egg is formed within the oogonium and sperms within the antheridium. *Volvox*, *Oedogonium*, *Chara*, *Vaucheria*, *Sargassum*, *Batrachospermum* and *Polysiphonia* are the common examples of oogamy.

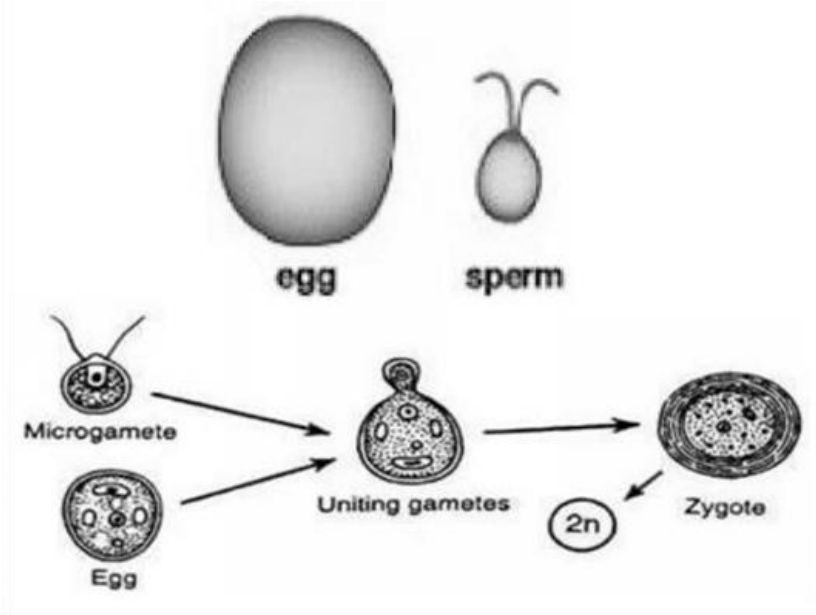

Figure-9.27: Oogamy in algae (https://tinyurl.com/vn5czt6s)

9.4 SUMMARY

Algae, diverse photosynthetic organisms ranging from unicellular to multicellular forms, exhibit varied nutritional strategies that adapt to their environments. Most algae are photoautotrophs, utilizing chlorophyll and other pigments (e.g., phycobilins in red algae) to convert sunlight, CO_2, and water into energy via photosynthesis. This process underpins their role as primary producers in aquatic ecosystems, contributing significantly to global oxygen production and carbon fixation. Some algae combine autotrophy with heterotrophic strategies, absorbing organic materials (osmotrophy) or engulfing particles (phagotrophy) when light or nutrients are limited. A minority of algae lack photosynthetic capability and rely entirely on organic carbon absorption. These are often found in dark or nutrient-rich environments. Algae frequently form mutualistic relationships, notably in lichens (with fungi) and coral reefs (as zooxanthellae), exchanging photosynthetic products for shelter or nutrients.

Algae reproduce through both sexual and asexual methods, depending on the species and environmental conditions. The asexual reproduction includes Binary Fission - In unicellular algae, like diatoms and green algae, asexual reproduction often occurs through binary fission, where the parent cell divides into two identical daughter cells. Fragmentation - In multicellular algae, pieces or fragments of the algae can break off and grow into new individuals. This is common in many seaweeds. Algae can produce spores that are typically released into the water, where they germinate under favorable conditions. In sexual reproduction, algae produce gametes

(male and female reproductive cells). Fertilization occurs when these gametes combine, leading to the formation of a zygote, which grows into a new individual. Sexual reproduction includes Isogamy - Gametes are of similar size and shape. Anisogamy - Gametes are of different sizes, with one being larger (female) and the other smaller (male). Oogamy - The female gamete is large (egg), while the male gamete is small (sperm). This type of sexual reproduction is seen in many green algae. Some algae also exhibit an alternation of generations, where they alternate between a haploid (gametophyte) and diploid (sporophyte) phase during their life cycle. Overall, algae are highly adaptable in their reproductive strategies, which contribute to their widespread presence in various ecosystems.

9.5 TECHNICAL TERMS

Spores, Amylum, Gametes, isogamy, anisogamy, oogamy

9.6 SELF ASSESSMENT QUESTIONS

Q.1 Describe the various modes of nutrition in algae.

Q.2 Explain the asexual reproduction in algae.

Q.3 Give a detailed account on sexual reproduction in algae.

9.7 SUGGESTED READINGS

1. Text Book of Algae, Awasthi, A. K., Vikas Publishing House.
2. College Botany Volume 1, Pandey, B. P., S. Chand, New Delhi.
3. A text book of Algae, Kumar, H.D.
4. Botany for Degree Students Algae, Vashishta, B. R., Sinha, A. K. and V. P. Singh., S. Chand, New Delhi.
5. A Text Book of Algae, Sambamurty, A. V. S. S., I.K International Publishing House Pvt. Ltd.

Prof. V. Umamaheswara Rao

LESSON – 10

CLASSIFICATION OF ALGAE

OBJECTIVE OF THE LESSON

Students are able to understand the various groups of algae and their classification based on different characteristics of various algal members.

STRUCTURE OF THE LESSON

10.1 INTRODUCTION

Classification is the systematic grouping of organisms into categories on the basis of relationships between them, where the relationship can be either evolutionary or structural. The hierarchy for the classification of plants is Division, Class, Order, Family, Genus and Species as per International code of botanical nomenclature (ICBN). Algae are the thalloid plants which contain various pigments that imparts colour to their body and hence be named according to their colour as green algae, brown algae, red algae etc. For the classification of algae, certain suffixes have been recommended by the committee of International Code for Nomenclature. These are phyta for division, phyceae for class, phycideae for sub-class, ales for order, inales for sub-order, aceae for family, oideae for sub-family. With the advancement of the techniques in the area of biochemistry, physiology, biotechnology, electron microscopy etc., different criteria like types of pigments, flagellation, reserve food material, pattern of life cycle etc. are used to classify the algae.

10.2 MODERN CONCEPT TO CLASSIFY ALGAE

Based on some criteria namely 1. Nuclear organization **2**. Cell wall components **3**. Pigments **4**. Flagellation 5. Chemical nature of reserve food material **6**. Type of life cycle and reproduction algae are classified into various classes.

1. Nuclear organization: On the basis of nuclear organization, algae can be prokaryotic or eukaryotic. Cyanophyceae or cyanobacteria (blue green) are prokaryotic in nature while all other algae are eukaryotic. In cyanophyceae, nuclear membrane is absent and genetic material (chromatin threads) is not bounded with histone proteins. Moreover, membrane bound organelles

like mitochondria, plastids, Golgi bodies, endoplasmic reticulum, vacuoles etc., are not found. Eukaryotic algae have well organized nucleus, mitochondria, Golgi bodies, chloroplasts, endoplasmic reticulum etc. in their cell structure.

2. Chemical composition of Cell wall: The cell wall of algae is made up of cellulose (polysaccharide). In general, the inner wall is insoluble cellulosic layer and outer wall is made up of pectic substances which are soluble in water. In addition to this certain classes of algae possess certain chemical components in their cell wall which make them distinct from other classes. For example, members of Phaeophyceae possess alginic acid and fucinic acid in their cell wall while silica is impregnated in the cell wall of Bacillariophyceae. Xylan and galactan are found in cell wall of Rhodophyceae. Cell wall of Cyanophyceaea is made up of by mucopeptide.

3. Pigments: It is one of the most important criteria of classification of algae. In the beginning, algae were classified as red algae, brown algae, green algae and blue green algae on the basis of their colour. Pigments are present in plastids of eukaryotic algae while in thylakoids of prokaryotic algae. Plastids contain three types of pigments in algae namely chlorophyll, carotenoids and phycobilins.

a) Chlorophyll: Five types of chlorophylls namely-chlorophyll a, b, c, d and e are found in algae. Chlorophyll a is present in all classes of algae. Chlorophyll b is present in Chlorophyceae and Euglenineae. Chlorophyll c is present in Phaeophyceae and Cryptophyceae. Chlorophyll d is found in Rhodophyceae only. Chlorophyll e is present in Xanthophyceae only.

b) Carotenoids: Carotenoids are yellow or orange coloured pigments. They are capable of absorbing destructive oxygen molecules from light and provide a protective sheath. The various colours in algae are due to these pigments. Carotenoids are of fat soluble and divided into carotene, xanthophylls and carotenoid acids.

Carotene: There are six types of carotenes- α, β, γ, ε, flavicine and lycopene. Carotene is a linear chain of unsaturated hydrocarbons and fat soluble. β-carotene is found in all classes of algae. α-carotene is found in Rhodophyceae and Cryptophyceae. γ-carotene and lycopene are found in Charophyceae. ε-carotene is present in Cryptophyceae and Bacillariophyceae. In Cyanophyceae, flavicin is found.

Xanthophyll: Xanthophylls are oxygen derivatives of carotenes. About 20 types of xanthophylls are found in algae. e.g., Zeathanthin, Flavoxanthin, Diatoxanthin, Myxoxanthin, Myxoxanthophylls, Fucaxanthin, Zeaxanthin, Ocillaxanthin, Terraxanthin etc. Myxoxanthin and Myxoxanthophyll are present only in Cyanophyceae, Terraxanthin only in Rhodophyceae, and Antheroxanthin only in Euglenineae.

Carotenoid acids: Carotenoid acid resembles with carotene and xanthophylls and are hydrocarbons, consisting a chain of carbon atoms.

c) Phycobilins or biliprotiens- Phycobilins are soluble in water. They are attached to a protein moiety. There are three types of phycobilins- phycocyanin, phycoerythrin and allophycocyanin. r-phycocyanin and r-phycoerythrin are confined to Rhodophyceae while c-phycocyanin and c-phycoerythrin are found in cyanophyceae. Allophycocyanin is found in Rhodophyceae.

4. Nature of reserve food material: The main reserve food material in algae is starch which is a product of photosynthesis. Due to accumulation of food over long period, the nature of reserve food material may be different. In Chlorophyceae, starch remains as the reserve food material. In Cyanophyceae, it is myxophycean starch. Floridean starch is found in Rhodophyceae. In Pheaophyceae, mannitol and laminarin are the main reserve food materials, while in Xanthophyceae, leucosine and oil are reserve food.

5. Flagellation: Flagella are the important basis of criteria to classify the algae. The type, number and position of flagella are different for different classes of algae. Flagella are entirely absent in Cyanophyceae and Rhodophyceae. There are two main types of flagella- whiplash or acronematic and tinsel or pleuronematic.

A. Whiplash or **acronematic:** It has smooth surface.

B. Tinsel or **pleuronematic:** tinsel flagellum bears longitudinal rows of fine, minute flimmers or mastigonemes. Tinsel flagella may be pantonematic, pantoacronematic or stichonematic.
i. Pantonematic- Mastigonemes are arranged in two opposite rows in the flagellum.

ii. Pantoacronematic- It is a pantonematic flagellum with terminal fibril.

iii. Stichonematic- Mastigonemes are present only on one side of flagellum.

In Chlorophyceae, flagella are of 2, 4 or indefinite in number, apical or sub-apical in position and acronematic type (isokontic- all flagella are of same type). In Xanthophyceae, flagella are two and unequal, apical in position (heterokontic-one whiplash and one tinsel). In Phaeophyceae, flagella are two, lateral and unequal (one whiplash and one tinsel).

6. Type of life cycle and reproduction: The presence or absence of sexual reproduction, complexity of reproductive organs, and method of reproduction is also considered as criteria to classify the algae. Haplontic, diplontic and triphasic life cycle are the characteristics of different groups. Sexual reproduction is completely absent in Cyanophyceae. In Rhodophyceae and Phaeophyceae, reproduction is oogamous and life cycles are usually complex. In Chlorophyceae, reproduction may be isogamous, anisogamous and oogamous, the life cycle may be simple or complex.

10.3 CLASSIFICATION

The history of classification dates back to Carolus Linnaeus, who first classified plants into 25 classes based on “sexual system” considering the number of stamens and carpels in their flowers. Out of his 25 classes, in “Cryptogamia” which contains plants with “concealed reproductive organs” Linnaeus, proposed 14 algal genera. W. H. Harvey is considered as one of the first algologist who proposed the first descriptive algal classification. Since W. H. Harvey, several classifications have been proposed based on a variety of characters including morphological, physiological, biochemical and more recently the molecular characters have also been considered.

The major classifications proposed by different algologists for algae

William Henry Harvey (1811–1866), was a pioneer algologist. He classified the algae for the first time in 1836 into four groups based on the colour of thallus 1. Chlorospermae (Green) 2. Melanospermae (Brown) 3. Rhodospermae (Red) 4. Diatomacea (Diatoms). Eichler (1883) placed both algae and fungi in one group Thallophyta. Further Eichler classified algae into five groups 1. Cyanophyceae (Blue green algae) 2. Diatomeae (Diatoms) 3. Chlorophyceae (Green algae) 4. Phaeophyceae (Brown algae) 5. Rhodophyceae (Red algae). Engler and Prantle (1887 –1915) in *Die Naturlichen Pflanzenfamilien*, algae and fungi were grouped into Euphyceae and Eumycetes and categorized into different groups (Table 10.1).

Table-10.1: Engler and Prantle classification

<table>
<tr><td>1</td><td>Schizophyta</td><td colspan="2">Cyanobacteria</td></tr>
<tr><td>2</td><td>Flagellate</td><td colspan="2" rowspan="2">Flagellate Protists</td></tr>
<tr><td>3</td><td>Dinoflagellate</td></tr>
<tr><td>4</td><td>Bacillariales</td><td colspan="2">Diatoms</td></tr>
<tr><td rowspan="5">5</td><td rowspan="5">Euphyceae</td><td rowspan="5">Algae</td><td>Conjugatae</td></tr>
<tr><td>Chlorophyceae</td></tr>
<tr><td>Charophyta</td></tr>
<tr><td>Phaeophyta</td></tr>
<tr><td>Rhodophyceae</td></tr>
<tr><td>6</td><td>Eumycetes</td><td colspan="2">Fungi</td></tr>
</table>

In 1916, West proposed a classification based on the reproductive structures and presence or absence of flagella. West divided algae into four categories 1. Isokontae (Flagella of equal size) 2. Akontae (Flagella absent) 3. Stephanokontae (Flagella crowned) 4. Heterokontae (Flagella of unequal size). A. Pascher (1931) proposed an evolutionary classification based on the phylogeny and interrelationships among various groups. In his classification, algae has been placed above the rank of a division. He classified algae into eight divisions which were further subdivided into different classes (Table 10.2).

Table-10.2: Pascher classification of algae

S.No	Division	Classes
1	Chrysophyta	(a) Chrysophyceae
		(b) Diatomeae
		(c) Heterokontae
2	Phaeophyta	Phaeophyceae
3	Pyrrophyta	(a) Cryptophyceae
		(b) Desmokontae
		(c) Dinophyceae
4	Euglenophyta	Euglenophyceae

5	Chlorophyta	(a) Chlorophyceae
		(b) Conjugatae
6	Charophyta	Characeae
7	Rhodophyta	(a) Bangineae
		(b) Floridineae
8	Cyanophyta	(a) Myxophyceae

During 1933, J. E. Tilden classified the algae based on reserve food material, pigmentation and flagellation. He classified algae into five classes. According to Tilden, pigments are of vital importance in the development and advancement of algal members and thus supported the retention of names of algae based on colours.

F. E. Fritsch (1935), also known as Father of Phycology, proposed the most acceptable and comprehensive algal classification. Fritsch published two volumes of "Structure and Reproduction of the Algae". His classification is based on different characteristics as pigmentation, chemical nature of reserve food material, flagellar arrangement, presence or absence of organized nucleus in cell and mode of reproduction (Table 10. 3). He emphasized the account of living forms of algae as compared to fossil forms, all of which have been grouped in one class. He classified algae into 11 classes. The characteristic features of different classes as proposed by Fritsch are as below.

Class Myxophyceae (Cyanophyceae)

The members are called as blue green algae and are prokaryotic. Thallus is simple, unicellular, colonial or multicellular bodies. Pigments are not in organized bodies as in other cases. Principle pigments are chlorophyll a, α-carotene, β- carotene, xanthophylls and phycobilins- c-phycocyanin and c-phycoerythrin. The colour of algae is due to the presence of excess c-phycocyanin. Reserve food material is cyanophycean starch. The cell wall is made up of by mucopeptide. Most of the members are embedded in mucilaginous sheath. False branching and special cells, heterocysts are the characteristics of several members. Motile cells are altogether absent in life cycle. Fritsch classified Myxophyceae into 5 orders.

1. Chroococcales (*Gleocapsa, Microcystis*)
2. Chamaesiphonales (*Chamesiphon, Dermocarpa*)
3. Pleurocapsales (*Pleurocapsa*)
4. Nostocales (*Nostoc, Oscillatoria, Anabaena, Gloeotrichia, Rivularia, Scytonema, Spirulina*)
5. Stigonematales (*Nostochopsis, Stigonema, Mastigocladium*)

Class Euglenophyceae

The class includes unicellular flagellates. Flagella are one or two in numbers. Members are fresh water forms or found in saline habitats. Mostly members are free swimming bodies but have tendencies to form gelatinous colonies. Major pigments are chlorophyll a and b, β- carotene and xanthophylls. Reserve food material is polysaccharide paramylon and fats. Reproduction usually takes place by fission. E.g. *Euglena, Heteronema,* etc.

Class Chlorophyceae

The Class possesses green algae. Main pigments are chlorophyll a and b, xanthophylls and carotenoids. The cells have well organized nucleus (eukaryotic). Reserve food material is starch rarely oil. Pyrenoid is usually present in the plastid. Motile cells have two isokontae flagella. Sexual reproduction ranges from isogamous to oogamous. The members are mostly fresh water but few forms are marine. Fritsch devided Chlorophyceae into 9 orders i.e. 1. Volvocales (*Volvox*) 2. Chlorococcales (*Chlorella*) 3. Ulothrichales (*Ulothrix*) 4. Cladophorales (*Cladophora*) 5. Chaetophorales (*Fritschiella*) 6. Oedogoniales (*Oedogonium*) 7. Conjugales (*Zygnema*) 8. Siphonales (*Vaucheria*) 9. Charales (*Chara*).

Class Chloromonadineae

Members are only fresh water forms. Algae of this class are bright green (olive green) in colour due to the presence of excess xanthophylls and cells have numerous discoid chromatophores. Reserve food material is fat. They reproduce by longitudinal division. Chloromonadineae includes only one order, Chloromonadales (*Vacuolaria, Trentonia*).

Class Xanthophyceae (Heterokontae)

Majority of the members are fresh water forms, few are marine. The members are yellow green in colour due to excess of xanthophylls. Major pigments are chlorophyll a and e, β- carotene and xanthophylls. Motile cells are biflagellate with two unequal flagella. Pyrenoids are not present in plastids. Reserve food material is fat. Sexual reproduction is rarely present but if present then it is isogamous. Unequal flagella and cell walls of equal or unequal length overlap. Fritsch divided this division in to 4 orders.

1. Heterochloridales (*Heterochloris, Chloramoeba*)
2. Heterococcales (*Myxochloris*)
3. Heterotrichales(*Tribonema*)
4. Heterosiphonales (*Botrydium*)

Class Chrysophyceae

Mostly the members are marine and fresh water forms. The colour of the algae is brown or orange due to the excess presence of phycochrysin and phycocyanin. In addition to this, other pigments present are chlorophyll a and β-carotene. Reserve food material is oil and leucosine. Phycochrysin is a pigment that imparts the characteristic yellow or orangish color. The plants are in colonial forms of unicellular or multicellular algae. Cell walls may or may not be present. When present, it is seen as overlapped halved. Algae have silicified cysts, and 1-3 flagella. Sexual reproduction is rare as in case of Xanthophyceae and if present then it is isogamous. Motile cells have one flagellum. Sometimes two or three flagella may also be present. Fritsch divided this division into 3 orders.

1. Chrysomonadales (*Chrysodendron*)
2. Chrysosphaerales (*Chrysosphaera*)
3. Chrysotrichales (*Chrysoclonium*)

Class Bacillariophyceae (Diatoms)

The members of Bacillariophyceae are commonly known as Diatoms. Members are both fresh water and marine forms. The dominant pigment is diatomin and yellow or golden brown in colour. Other pigments, chlorophyll a and c, β- carotene and xanthophylls are also seen. Cell wall is impregnated with silica and variously ornamented. The wall is divided into two halves. Pyrenoids are present. Reserve food material is oil, volutin and leucosine. The habits are unicellular and non-motile. The cell wall is silicified and contains pectose. They are symmetrical in appearance with delicate markings on them. Bacillariophyceae consists of just 2 orders.

1. Centrales (*Cyclotella, Chaetoceras*)
2. Pennales (*Grammatophora , Navicula*)

Class Cryptophyceae

The members are both fresh water and marine. The members are variously coloured (brown, red, olive green, or sometimes bluish green). The cells have two large parietal chloroplasts with pyrenoids. Reserve food material is starch. Motile cells are biflagellate which are unequal in length. Each cell with 2 two large parietal chloroplasts, two unequal flagella, and endogenous cysts are present. Sexual reproduction is unique and is isogamous. Cryptophyceae has only two orders.

1. Cryptomonadales (*Cryptomonas*, *Chilomonas*)
2. Cryptococcales (*Tetragonidium*)

Class Dinophyceae (Peridineae)

The colour of the members is brown or dark yellow due to the presence of red phycopyrin, dark red peridinin and yellow green chlorophyllin. Most of the members are unicellular, motile, filamentous, longitudinal and transverse furrow, large nucleus and discoid chromatophores, cell wall sculptured, biflagellate. The reserve material is oil or starch. E.g. *Heterocapsa, Ceratium, Peridinium*, etc. Disc shaped chloroplasts are present. Chlorophyll a and c are present. Reserve food material is starch and fat. Sexual reproduction is rare and if present then it is isogamous. Fritsch divided Dinophyceae into 6 orders.

1. Desmomonadales (*Desmocapsa*)
2. Dinophysales (*Dinophysis*)
3. Thecatales (*Exuviaella*)
4. Dinoflagellata (*Ceratium*)
5. Dinococcales (*Cystodinium*)
6. Dinotrichales (*Dinothrix*).

Class Phaeophyceae

The members are generally known as brown algae. Structurally these are the most complex algae. Filamentous or organized seaweeds, flagella on both sides- one for forward and the other for backward movement, produce uni, or plurilocular sporangia. Pigments include chlorophyll a and c, β- carotene and xanthophylls. The brown colour is due to excess of fucoxanthin. Commonly algae are called sea weeds. They are marine forms. Reserve food material is in the form of laminarin and mannitol. Algin and fucoidin are present in cellulosic cell wall. Reproduction is by vegetative and sexual both. Sexual reproduction ranges from isogamy to oogamy. Motile cells are biflagellate with unequal length. Zoospores are biciliated with unequal ones. The zygote does not undergo any resting period. Phaeophyceae has 9 orders.

1. Ectocarpales (*Ectocarpus*)
2. Tilopteridales (*Tilopteris*)
3. Cutleriales (*Cutleria*)
4. Sporochnales (*Sporochnus*)
5. Desmarestiales (*Desmarestia*)
6. Laminariales (*Laminaria, Macrocystis*)
7. Sphacelariales(*Sphacelaria, Haploteris*)
8. Dictyotales (*Dictyota*)
9. Fucales (*Fucus, Sargassum*).

Class Rhodophyceae

Majority of the forms are marine and only few are fresh water forms. Members are called red algae. Major pigments include chlorophyll a and d, β- carotene, xanthophylls and phycobilins- r-phycoerythrin, r-phycocyanin and allophycocyanin. The colour of algae is red due to the presence of excess r-phycoerythrin. Reserve food material is floridean starch. Thallus is organized and possesses complexity. Filamentous or highly organized body, protoplasmic connections between cells, cystocarps produce carpospores that germinate to form tetrasporic diploid plants. Plasmodesmata is present in the cells except in the members of Protoflorideae. Sexual reproduction is specialized and oogamous. Motile cells are altogether absent. The reserve food material here is floridean starch. Rhodophyceae is divided into 7 orders.

1. Bangiales (*Bangia, Porphyra, Porphyridium*)
2. Nemalionales (*Batrachospermum, Nemalion*)
3. Gelidiales (*Gelidium*)
4. Cryptonemiales (*Corallina*)
5. Gigartinales (*Gigartina, Gracilaria*)
6. Rhodymeniales (*Champia, Rhodymenia*)
7. Ceramiales (*Ceramium, Polysiphonia*).

Apart from these 11 classes, Nematophyceae, a fossil group with two genera, was also suggested by Fritsch. True affinities of this class are unknown but their internal morphology is similar to Chlorophyceae. Their spore tetrads are similar to Rhodophyceae.

Table-10.3: Fritsch classification of algae

Class	**Occurrence**	**Pigments**	**Reserve food**	**Structure**	**Reproduction**
Chlorophyceae	Mostly freshwater some marine	Chl *a*, Chl *b*, carotenoids	Starch	Unicellular motile, heterotrichous branched	Isogamous to oogamous
Xanthophyceae	Mostly freshwater, some marine	Yellow xanthophylls	Oil	Unicellular motile, filamentous.	Isogamous
Chrysophyceae	Cold freshwater and marine	Brown or orange, Phycochrysin accessory pigment	Fat, leucosin	Unicellular motile, branched ilamentous, unequal anterior flagella, two parietal chromatophores	Isogamous
Basillariophyceae	All habitats	Yellow or golden brown	Fat, volutin	Unicellular colonial.	Diploid forms, plasmogamy
Cryptophyceae	Marine and freshwater.	Diverse pigments and usually parietal	Carbohydrates and starch.	Motile cells in coccoid with unequal flagella	isogamous
Dinophyceae	Marine planktons, a few freshwater forms	Chromatophores are dark yellow and brown.	Starch, oil	Unicellular motile or branched filaments	Isogamous

Chloromonadineae	Freshwater	Chromatophores bright green, excess chlorophyll	Oil	Motile with two equal flagella	Chromatophores are dark yellow, and brown
Eugleninae	Freshwater	Longitudinal division	Polysaccharide, Paramylon	Motile, anterior flagella one or two, large nucleus, pro minent vascular system.	Isogamous
Phaeophyceae	Marine	Chl a, Chl c, carotenes, xanthophylls	Mannitol, laminarin, fats.	Simple filamentous or bulky parenchymatous, giant size with internal differentiation.	Isogamous to oogamous with varied types of life cycles
Rhodophyceae	Fresh water and marine	Chromatophores red-blue r-phycoerythrin, r-phycocyanin, Chl a, Chl d, and carotenes	Filamentous, complex structures, no motiles known.	Floridean starch	Oogamous and later carpospores
Myxophyceae (Blue-green algae)	Marine, freshwater, moist places	Chlorophyll, carotenes, xanthophyll, c-phycocyanin and c-phycoerythrin	Sugars, glucogen	Filamentous, with true or false branching, rudimentary nucleus, ps pigments through the cell, non-motile	Fission, No sexual reproduction

In 1955, G. M. Smith supported the classification proposed by Pascher (1914, 1931) and proposed a new classification with certain modifications. He divided algae into divisions and further into classes. The seven divisions of algae are - **1**. Chlorophyta e.g. *Volvox, Chara* **2**. Euglenophyta e.g. *Euglena* **3**. Pyrrophyta e.g. *Desmarestia*, e.g. *Dinophysis* **4**. Chrysophyta e.g. *Chromolina, Botrydium,* e.g. *Pinnularia* **5**. Phaeophyta e.g. *Ectocarpus, Mynomena, Sargassum* **6**. Cyanophyta e.g. *Nostoc, Anabaena* and **7**. Rhodophyta e.g. *Polysiphonia, Gracilaria* , *Batrachospermum*. Smith also recognized algae of uncertain systematic position and placed them under chloromonadales and cryptophyceae.

G. E. Papenfuss (1955) proposed algal classification based on phylogenetic relationship. He recognized 7 divisions and 12 classes. The blue green algae were kept together in a separate phylum namely Schizophyta along with bacteria. The seven divisions are 1.Chlorophycophyta 2. Charophycophyta 3. Euglenophycophyta 4. Chrysophycophyta 5. Pyrrophycophyta 6. Phaeophycophyta 7. Rhodophycophyta

Chapman (1962) considered the pigments, morphological characters, biochemical differences and also phylogenetic relationships with in different algae for its classification. He divided algae into four different divisions 1. Euphycophyta 2. Myxophycophyta 3. Chrysophycophyta and 4. Pyrrophycophyta. Christensen (1964), divided algae on the basis of prokaryotic and eukaryotic features of cell into Prokaryota and Eukaryota. Prescott (1969) classified the algae based on the presence or absence of true nucleus, pigmentation, biochemical nature of cell wall, reserve food material, life history and reproduction. Based on these criteria he classified algae into nine phyta with different classes, i.e. 1. Chlorophyta 2. Euglenophyta 3. Chrysophyta 4. Pyrrophyta 5. Phaeophyta 6. Rhodophyta 7. Cyanophyta 8. Cryptophyta 9. Chloromonadophyta.

F. E. Round (1973) divided algae on the basis of presence or absence of true nucleus, membrane bound organelles and phylogenetic relationships etc. He classified algae into 12 phyla and further into classes, 1. Prokaryota 2. Eukaryota 3. Chlorophyta 4. Charophyta 5. Prasinophyta 6. Xanthophyta 7. Haptophyta 8. Dinophyta 9. Bacillariophyta 10. Chrysophyta 11. Phaeophyta 12. Rhodophyta. V. J. Chapman and D. J. Chapman (1973) classified algae into Prokaryota and Eukaryota. Bold and Wynne (1978) followed the classification proposed by Papenfuss and they accepted the use of “phyco” before “phyta” in algal divisions. They divided algae into nine divisions 1. Cyanochloronta 2. Chlorophycophyta 3. Charophyta 4. Euglenophycophyta 5. Phaeophycophyta 6. Chrysophycophyta 7. Pyrrophycophyta 8. Cryptophycophyta 9. Rhodophycophyta.

10.4 SUMMARY

Classification is a systematic grouping of organisms into categories based on relationships between them, whether evolutionary or structural. Algae are classified into various classes based on factors such as nuclear organization, cell wall components, pigmentation, flagellation, chemical nature of reserve food material, and type of life cycle and reproduction. William Henry

Harvey, a pioneer algologist, classified algae in 1836 into four groups based on the color of their thallus: Chlorospermae (Green), Melanospermae (Brown), Rhodospermae (Red), and Diatomacea (Diatoms). Eichler later placed both algae and fungi in one group, Thallophyta, and further classified algae into five groups: Cyanophyceae (Blue green algae), Diatomeae (Diatoms), Chlorophyceae (Green algae), Phaeophyceae (Brown algae), and Rhodophyceae (Red algae). F. E. Fritsch, also known as the Father of Phycology, proposed the most acceptable and comprehensive algal classification in 1935. He classified algae into 11 classes, including Myxophyceae (Cyanophyceae), Chlorophyceae, chloromonadineae, Xanthophyceae (Heterokontae), Chrysophyceae, Bacillariophyceae (Diatoms), Cryptophyceae, Dinophyceae (Peridineae), Phaeophyceae, and Rhodophyceae. G. M. Smith supported Pascher's classification and proposed a new classification with modifications in 1955. He divided algae into divisions and further into classes, including Chlorophyta, Euglenophyta, Pyrrophyta, Chrysophyta, Phaeophyta, Cyanophyta, and Rhodophyta. G. E. Papenfuss proposed algal classification based on phylogenetic relationship, recognizing seven divisions and 12 classes. Chapman (1962) considered pigments, morphological characters, biochemical differences, and phylogenetic relationships for classification. He divided algae into four different divisions: Euphycophyta, Myxophycophyta, Chrysophycophyta, and Pyrrophycophyta. Christensen (1964) divided algae based on prokaryotic and eukaryotic features of cells into Prokaryota and Eukaryota. Prescott (1969) classified algae based on the presence or absence of true nucleus, pigmentation, biochemical nature of cell wall, reserve food material, life history, and reproduction. F. E. round (1973) classified algae into 12 phyla and further into classes, including Prokaryota, Eukaryota, Chlorophyta, Charophyta, Prasinophyta, Xanthophyta, Haptophyta, Dinophyta, Bacillariophyta, Chrysophyta, Phaeophyta, and Rhodophyta. Parker (1982) classified algae into Prokaryota and Eukaryota based on membrane-bound organelles, while Lee (2008) classified algae into two groups: Prokaryota and Eukaryota, which were further divided into divisions. In summary, classification is a systematic grouping of organisms based on various criteria, including nuclear organization, cell wall components, pigmentation, flagellation, chemical nature of reserve food material, and life cycle and reproduction.

10.5 TECHNICAL TERMS

Pigments, Carotenoid, Diplontic, Haplontic, Isogamous, Reserve food, Starch, Flagellum.

10.6 SELF ASSESSMENT QUESTIONS

Q.1 Describe the main criteria used to classify the algae.

Q.2 Give the classification of algae given by Smith.

Q.3 Describe the distinguishing features of chlorophyceae, Phaeophyceae, Xanthophyceae, and Rhodophyceae.

Q.2 Give a detailed account of classification proposed by F. E. Fritsch.

10.7 SUGGESTED READINGS

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LESSON – 11

ECONOMIC IMPORTANCE OF ALGAE

OBJECTIVE OF THE LESSON

Students will know the role of algae in synthesis food and their significant role in medicinal, commercial and industrial aspects.

STRUCTURE OF THE LESSON

11.1 INTRODUCTION

Algae are economically important as they contribute to various industries, including food, pharmaceuticals, biofuels, and agriculture. They are rich in proteins, vitamins, and essential fatty acids, making them valuable as human food (e.g., seaweed) and animal feed. Algae are also used in pharmaceuticals for their antioxidant and anti-inflammatory properties. In biofuel production, microalgae are a promising source of biodiesel due to their high lipid content. Additionally, algae play a role in wastewater treatment by absorbing pollutants and in agriculture as biofertilizers to enhance soil fertility. Their diverse applications make them crucial for sustainable economic development.

Single cell protein (SCP) refers to edible protein derived from microorganisms such as bacteria, yeast, fungi, or algae, cultivated under controlled conditions to produce nutrient-rich biomass. As global population growth and environmental challenges strain traditional protein sources like

livestock and crops, SCP emerges as a sustainable alternative, offering high protein content, rapid production cycles, and minimal resource requirements. Unlike conventional agriculture, SCP production can utilize low-cost substrates, including agricultural waste, industrial by-products, or renewable feed stocks, reducing reliance on arable land and freshwater. Its applications span animal feed, aquaculture, and potential human consumption, addressing food security while aligning with circular economy principles by repurposing waste streams. With the added benefit of lower greenhouse gas emissions compared to livestock farming, SCP represents a promising innovation in meeting future nutritional demands and advancing environmental sustainability.

Algal blooms, rapid proliferations of algae in aquatic ecosystems, pose significant environmental and public health challenges globally. Often fueled by nutrient pollution from agricultural runoff, wastewater discharge, and industrial activities combined with warm temperatures and stagnant waters, these blooms can form dense, visible mats in both freshwater and marine environments. Among them, harmful algal blooms (HABs) are particularly concerning due to their production of potent algal toxins, such as microcystins, saxitoxins, and domoic acid. These toxins disrupt aquatic ecosystems by depleting oxygen, creating dead zones, and poisoning marine life, which cascades through food webs. Human exposure, through contaminated drinking water, recreational activities, or consumption of tainted seafood, can lead to severe health issues, including neurological impairments, liver damage, and respiratory distress. The escalating frequency of HABs, linked to climate change and eutrophication, underscores the urgent need for coordinated monitoring, sustainable nutrient management, and public awareness to mitigate their ecological and socioeconomic impacts.

11.2 ALGAE AS PRIMARY PROODUCERS

Algae play a fundamental role in ecosystems as primary producers, they form the base of the food chain by converting sunlight into organic matter through photosynthesis. They produce oxygen and serve as a crucial food source for various organisms in aquatic ecosystems.

1. Photosynthesis and Energy Production

Both fresh and saltwater contain an enormous variety of algae which constitute the fundamental or primary link of many diverse food chains. Algae synthesize organic food stuffs, just as do the plants of the land. Algae, like plants, use chlorophyll to capture sunlight and convert carbon dioxide (CO_2) and water into glucose (organic matter) and oxygen. This process supports aquatic ecosystems by supplying energy to herbivores (such as zooplankton and small fish) and higher trophic levels.

$$6CO_2+6H_2O+\text{Light}\rightarrow C_6H_{12}O_6+6O_2$$

2. Algae as the Base of the Food Chain

Microalgae (phytoplankton) like single celled algae such as diatoms and dinoflagellates serve as food for zooplankton. Macroalgae (seaweeds) such as larger algae, like kelp and sea lettuce, are consumed by herbivorous marine animals such as sea urchins and fish. Higher organisms, including predatory fish, birds, and mammals, depend on this foundation.

3. Oxygen Production and Global Impact

Algae contribute to over 50% of the world's oxygen supply, making them crucial for maintaining atmospheric balance. Marine phytoplankton, particularly diatoms and cyanobacteria, play a significant role in global oxygen production.

4. Carbon Sequestration and Climate Regulation

Algae absorb carbon dioxide (CO_2) from the atmosphere, helping to reduce greenhouse gases. Some carbon gets stored in deep ocean sediments when algae die and sink, contributing to long-term carbon sequestration.

5. Role in Aquatic Ecosystem Stability

Algae provide habitat and shelter for small aquatic organisms. Their presence influences nutrient cycling, maintaining water quality by absorbing excess nutrients.

6. Agricultural importance

Blue green soil algae are very important in agriculture as they are capable of nitrogen fixation in the soil. Some important soil cyanobacteria are *Tolipothrix tenius, Aulosira fertilissima, Anabaenopsis, Oscillatoria, Anabaena, Nostoc, Spirulina* and *Cylindrospermum*. Cyanobacteria neutralize the alkalinity and increase fertility of the soil. Sea weeds are used as biofertilizers. The agricultural utilization of sea weeds such as kelps and red algae used as manure for centuries. Kelps and red algae are rich in potassium. Sea weeds are sometimes burnt and their ashes are sprinkled over the agricultural land as common practice in some countries. Concentrated liquid extracts of sea weeds are sold as fertilizers and insecticides. The grinded form of *Lithothamnion, Lichophyllum* and *Chara* are used in place of lime in some countries.

7. Role of algae as food and fodder

Algae synthesize organic food stuffs and are an important food source of fishes and other aquatic animals. Diatoms, filamentous and some planktonic green algae, and a number of blue-green algae are very common fish food. Many brown, red and green algae are part of regular human diet at global level. In India, *Spirogyra* and *Oedogonium* are important genera. *Ulva lactuca* was used as salad in Scotland. *Porphyra* (good source of vitamin B and C) is used in large scale as common item of diet in England, China, Japan and South Korea. Kombu, a Japanese food is prepared by stipes of *Laminaria.* It has been estimated that approximately 25% of the daily diet in China and Japan consists of sea weeds. The algae are considered rich in proteins, fats and vitamin A, B, C and E. Apart from this the milk yielding capacity of the cattle is enhanced when dried sea weeds used as cattle feed.

11.3 COMMERCIAL PRODUCTS FROM ALGAE

1. Algae as the origin of petroleum and gases

The fuels such as petroleum and gases have their origin in the organic matter of the marine environment. Planktons captured the energy from sunlight during photosynthesis and transferred to the marine animals in the form of food. Organic compounds derived from the planktons and

the animals accumulated in the mud deposits of the ocean floor. The sedimentary action in an oxygen free environment of source materials converted gradually into oil and gas. Natural gas is largely methane (CH_4), which can be produced by certain kinds of anaerobic bacteria. Gas is generally associated with oil and can result from the action of methane-producing bacteria upon organic compounds.

2. Role of algae in medicine

Ancient literature of China revealed the use of *Laminaria* sp. for the treatment of goiter. Brown algae being rich source of iodine are employed in the preparation of medicines for goiter. Members of Laminariales have long been used as a surgical tool and also during child birth to expand the cervix. An antibiotic chlorellin is obtained from *Chorella.* Agar agar is an important algal product obtained from red algae used in the manufacture of pills and ointments by pharmaceutical industries. Carrageenin and alginic acid acts as blood coagulant. Extracts of *Digenea, Codium, Alsidium* and *Durvillea* are effective vermifuge. In Unani medicine system, many algae are used in the treatment of lung, kidney and bladder ailments. Extracts of *Cladophora* and *Lyngbya* possess antiviral properties.

3. Role of algae in sewage disposal

Species of *Chlamydomonas, Chlorella, Scendesmus* and *Euglena* are used in sewage tanks for providing effective, rapid and cheap means of converting the sewage into an odourless and valuable fertilizer. These tanks promote growth of algae in the expense of sewage and these algae photosynthesize and thus produce oxygen for the microorganisms. These microorganisms decompose the organic matter of sewage.

4. Algae and limestone formation

Many species of algae withdraw calcium from water, and deposit it in the form of calcium carbonate, in their cell walls. Blue green algae, red algae and some dinoflagellates play a significant role in this process. Fresh water blue green algae are chiefly responsible for the extensive formation of limestone deposits around hot springs and glaciers. The red algae are the most important calcareous algae of the seas and in particular they play an important role in the formation of coral reefs together with the cnedarians. The algae are also played important role in the production of beds of limestone rocks.

5. Algae used in Space research

Algae like *Chlorella* (space algae) *Scenedesmus* and *Synchococcus* are used as food source for space travelers. Chlorella has been found very suitable for keeping the air in space vehicles pure on long interplanetary flights. These algae are very rich in proteins (single cell protein) and multiply rapidly and thus synthesize a rich harvest of food utilizing carbon dioxide and liberating sufficient oxygen as a byproduct for use. These algal species *Chlorella, Chlamydomonas,* and *Acetabularia* are used as tools for solving fundamental biochemical and genetical problems.

6. Algae is used as Fertilizers

Use of seaweeds as soil fertilizer is a traditional process globally. The yields of paddy is increased on inoculation with nitrogen fixing blue-green algae. E.g.: *Aulosira fertilissima, Anabaena oryzae, Anabaenopsis arnoldii, Calothrix confervicola, Cylindrospermum bengalense* and *Nostoc commune.*

11.4 ROLE OF ALGAE IN INDUSTRIES

The industrial utilization of algae particularly sea weeds have been known from hundreds of years. The products obtained from algae have various industrial uses. The major products derived from algae are algin, agar agar, carrageenin, diatomite and kelp.

a) Agar-agar: It is a mucilaginous product obtained from red algae that is stored in their cell walls along with cellulose. The main source of agar-agar producing algae is *Gelidium, Gracilaria* and *Gigartina.* Agar is used extensively in microbiology laboratories as a base for the culture media for bacteria, fungi etc. In pharmaceutical industries, Agar agar is used in the preparation of various medicines, especially as a laxative. It has a great value in the preparation of the food stuffs like breads, pastries, cheese, jellies, deserts and in dairy products as an antidrying agent. In meat industries, agar has proved its effectiveness for temporary preventive for meat and fish canning. Agar is used extensively in the cosmetic, leather, textile and paper industries too. Other genera which are used for this purpose includes *Camphylophora, Eucheuma, Hypnea, Ahnfeltia* and *Furcellaria.*

b) Algin: Algin is a carbohydrate found in the middle lamella and primary walls of brown algae. Algin or alginates are soluble calcium magnesium salt of alginic acid. Alginic acid is insoluble extract. The alginates having remarkable water absorbing qualities are used as thickeners in the food industry, cosmetics and in textile industry as printing pastes. They are of great use in the production of plastic and artificial fibers. Algin is used as emulsifier in confectionary, dental impression, powders, paints and ice-creams. They are also used in the rubber industry and in latex production. The chief sources of alginic acid are *Ascophyllum, Laminaria, Lessonia, Ecklonia, Macrocystis, Sargassum, Fucus* and *Eisenia.*

c) Carrageenin: The chief source of carrageenin is a red alga *Chondrus crispus* (Irish moss) and *Gigartina*. It is used as an emulsifying and stabilizing agent in food, textile, pharmaceutical, leather and brewing industries. It is also an important component of tooth pastes, deodorants, cosmetics and paints and also as a remedy for cough.

d) Diatomite: Diatomite or kieselguhr is a rock like deposits of indestructible, siliceous cell walls of dead diatoms (fossil diatoms) that had collected over many millions of years on the bottom of seas as sediments. The great deposits of this material, known as diatomaceous earth are found in many parts of the world. It is highly porous, insoluble, chemically inert, fire proof and highly absorbent. So as it is used for filtration process in oil refineries, sugar industries and for clearing solvents. It is used as insulator of refrigerators, boilers, hot and cold pipes, hollow tile bricks for construction of constant temperature rooms, sound proof rooms, in packing corrosive chemical liquids, in manufacture of dynamite etc. It is also used as a constituent of

tooth pastes, as a base on automobile and silver polishes. Diatomite was also used as an absorbent of nitroglycerine in the manufacture of dynamite.

e) Kelp: Brown algae (Kelp ash) are the source of iodine, soda, and potash. In Japan alone produces approx 100 tons of iodine annually form kelps. The chief genera that are employed for production of iodine are *Laminaria, Fucus, Ecklonia, Ascophyllum, Saccorhiza* and *Eisenia.*

f) Other industrial uses- Bromine is obtained from red algae *Rhodomela* and *Polysiphonia.* Glue (funori) is manufactured from red alga *Gleopeltis furcata*.

g) Algae as indicator of industrial wastes: Various species of algae are important indicators of industrial wastes such as paper mill wastes, oil wastes, distillery wastes etc. E.g. *Ulothrix zonata, Cymbella vantricosa, Surirella ovate* (paper mill wastes); *Diatoma vulgaris, Synedra acus* (oil wastes); *Chlorogonium gracillima, Chlamydobotrys* sp. (distillery wastes); *Callothrix braunii, Scendesmus obliquus, Navicula viridula, Cymbella ventricosa* (copper wastes); *Sureilla linearis, Acanthes affinis* (iron wastes); *Euglena acus, E. oxyuris* (iron wastes); *Ceratoneis arcus, Fragillaria virescens* (phenolic wastes).

11.5 ALGAE AS SINGLE CELL PROTEIN

The term 'Single Cell Protein' (SCP) is popularly known for a protein derived from microorganisms. It was coined by Wilson to replace the 'microbial' or 'bacterial' protein or 'petroprotein'. It was recognized that protein malnutrition is usually far more severe than that of other foods. The limitations of conventional sources of proteins were recognized. These include: a) Possible crop failure due to unfavourable climatic conditions in case of plants b) The need to allow a time lapse for the replenishment of stock in case of fish c) The limited land available for farming in case of plant production. On the other hand the production of SCP has a number of attractive features like a) It is not subject to the alterations/change of the weather and can be produced every minute of the year. b) Microorganisms have a much more rapid growth than plants or animals. Thus a bullock weighing 10000 kg weight would synthesize less than 400 grams (ie., 1/10000 of its weight) of protein a day, at the same time 10000 kg weight of microbes would probably produce over 50 tons (or over 100 times) of their own weight of protein a day. (c) Waste products can be turned into food in the production of SCP. During the First World War (1914-1918) baker's yeasts, *Saccharomyces cerevisiae*, were grown on a molasses-ammonium medium. Development continued in between the wars and in the Second World War (1939-1945), *Geotrichum lactis, Endomyces vernalis,* and *Candida utilis* were grown for food.

Substrates for single cell protein production

Even though, SCP are produced from microbes, but for the growth of microbes substrates as energy sources are must. Wide varieties of substrates have been used for SCP production and include hydrocarbons, alcohols, and wastes from various sources.

Hydrocarbons: Traditionally used substrates for SCP production. Different hydrocarbons have been used such as a) Aliphatic hydrocarbons b) n-Alkanes c) Unsaturated compounds d) Branched chain compounds. Hydrocarbon substrates are of two types.

1. Gaseous hydrocarbons: Among the gaseous hydrocarbons, methane has been most widely studied as a source of SCP. Others which have been studied include propane and butane. Single

cell protein production from methane has used continuous cultures and a mixed population of microorganisms. The advantages of mixed methane are higher growth rate, higher yield coefficient, greater stability resistance to contaminations and a reduction in foam production.

2. Liquid hydrocarbons

The major source of liquid hydrocarbons is crude petroleum. These hydrocarbons were first studied as a source of microbial vitamins and lipids.

Alcohols: Alcohols also acts as substrates for single cell protein. These includes 1. Methanol 2. Ethanol.

1. Methanol: Methanol is suitable as a substrate for SCP as it (a) is highly soluble in water (b) is minimal explosion hazard of methanol (c) is readily available (d) can be readily purified in a process (e) requires less oxygen than methane for metabolism by micro-organisms.

2. Ethanol: It is produced by the hydration of ethylene. Although ethanol can be utilized ordinarily by many bacteria and yeasts, as a substrate for SCP, it is largely used by yeasts. Ethanol has various advantages (a) It is already consumed in alcoholic beverages (b) Highly miscible with water (c) Ethanol in contrast with methane can be more safely stored and transported (d) It is non-toxic it can be more easily handled (e) Ethanol is partially oxidized.

Waste products

A large number of reports of SCP production from waste material have been reported which includes (i) Plant/wood wastes (ii) Starch-wastes (iii) Dairy wastes (iv) Wastes from chemical industries (v) Molasses

Other than these, a wide variety of substrates may also be used for SCP production. These include coffee wastes, coconut wastes, palm-oil wastes, citrus waste, etc.

Characteristics of organisms for SCP production

In order to produce SCP, the microorganisms used as SCP producers should have the following characteristics (a) Absence of pathogenicity and toxicity (b) Protein quality and content (c) Digestibility and organoleptic qualities (d) Growth rate (e) Adaptability to unusual environmental conditions (f) Strains which grow at low pH conditions or at high temperature are often chosen. The heterotrophic microorganisms currently used for SCP production are fungi, algae and bacteria.

Algae popularly used for SCP production

Several species of *Arthrospira*, *Chlorella*, *Scenedesmus*, *Euglena*, *Dunaliella*, *Nostoc*, *Anabaena*, *Gelidium*, *Gracilaria*, *Phaeodactylum*, *Haematococcus* etc.

SCP production process

Single cell Protein production process commonly has these following steps 1. Microbial screening 2. Choice of raw materials 3. Process engineering and process optimization 4. Technology development 5. Economic consideration / Process feasibility 6. Safety concerns

1. Microbial screening: Microbial Screening is the first step in production process, suitable microbe which yields good amount of protein need to be selected. Microbial strains are collected from various habitats like soil, water, air and or from other biological materials. Microbes are selected by various studies including mutagenesis and other genetic methods, sometimes wild types are also used.

2. Choice of raw material: This part is little cumbersome and one need to focus on the correct composition of carbon supplement which yields higher biomass production in lesser time need to be analyzed. Various carbon sources are like wood waste, straw, other food processing wastes are also can be tried to optimize higher biomass production.

3. Process engineering: The technical conditions of cultivation for the optimized strains are done and all metabolic pathways and cell structures will be determined.

4. Technology development: Technology development is the next step where the adoption of the technical performance of the process in order to make the production ready for use on the large technical scale.

5. Economic factors: Energy consumption, cost of production are the important factor while going for large scale production phase, this need to be thoroughly analyzed and an energy efficient process need to be developed or else it will end up with loss.

6. Safety demands and Environmental protection: Since the SCP produced is for human consumption or for feeding animals, safety of the product need to be tested. Certain microbes produce toxic compounds which can have detrimental effect on humans and also for the environment, so the whole process should be monitored properly.

Advantages of Single Cell Protein

1. Single cell proteins have high protein and low fat content.
2. Single cell proteins are good source of vitamin.
3. It can be produced throughout the year.
4. Generation time of microbes is less, i.e., they multiply rapidly building up the biomass, more the biomass more the protein source.
5. During the production of SCP biomass, certain microbes produce useful by-products such as organic acids.
6. Waste (wood waste, food processing waste, hydrocarbons, etc) can be used as a source for carbon for growing microbes.
7. Doesn't require sophisticated lab setup for algae and certain other microbes.
8. High efficiency substrate conversion.

Disadvantages of Single Cell Protein

1. Single Cell Protein diet supplements can pose allergic reaction.
2. Consuming SCP, in-taking higher amount of nucleic acids which can lead to gastrointestinal problems.
3. Food grade SCP production is expensive.
4. Many microbes produce various toxic compounds.

11.6 ALGAL BLOOMS

An algal bloom is a rapid increase or accumulation of algae in a water body, often resulting in a green, red, or brown discoloration of the water. These blooms are typically caused by excess nutrients, particularly nitrogen and phosphorus, which can come from agricultural runoff, wastewater discharge, or other sources of pollution.

Types of Algal Blooms

1. **Harmful Algal Blooms (HABs):** Some algae produce toxins that can be harmful to marine life, humans, and pets. E.g. **red tides** caused by dinoflagellates like *Karenia brevis*.
2. **Non-Toxic Algal Blooms:** These are not directly toxic, but excessive algae can deplete oxygen in the water when they decay, leading to hypoxia (low oxygen levels) and death of fish.

Causes of Algal Blooms: Algal blooms are caused due to various factors which include nutrients, temperature, stagnant water, sunlight and climate change.

1. **Nutrient Pollution** – Excess fertilizers, sewage, and industrial runoff introduce nitrogen and phosphorus into water bodies.
2. **Warm Temperatures** – Higher water temperatures promote algal growth.
3. **Still or Slow-Moving Water** – Algae thrive in stagnant or slow-moving water.
4. **Sunlight** – Algae require sunlight for photosynthesis.
5. **Climate Change** – Rising temperatures and changing precipitation patterns increase the frequency of blooms.

Harmful Algal Bloom (HAB) Species: Several species of algae are responsible for harmful algal blooms, including 1.Cyanobacteria 2. Dinoflagellates and 3. Diatoms.

1. Cyanobacteria (Blue-Green Algae): Cyanobacteria produce toxins like Microcystins, Anatoxins, Cylindrospermopsins. These toxins can creates the Liver damage, neurotoxicity, skin irritation. E.g. *Microcystis, Anabaena, Aphanizomenon*

2. Dinoflagellates (Cause of Red Tide): Brevetoxins, Saxitoxins, Ciguatoxins are the toxins produced by dinoflagellates. These toxins causes fish death, respiratory issues in humans, and neurotoxic to shellfish. E.g. *Karenia brevis, Alexandrium, Gambierdiscus*

3. Diatoms: The Domoic aicd is the toxin produced by diatoms. This toxin generally causes Amnesic shellfish poisoning, neurological damage in humans and marine mammals. E.g. *Pseudo-nitzschia*.

Effects of Algal Blooms: Algal blooms showed varied negative impacts on both plants and animals. The major effects due to algal blooms are given here under.

Oxygen Depletion: When algae die and decompose, they consume oxygen, leading to dead zones where fish and marine life cannot survive.

Toxins: Some algae, like cyanobacteria (blue-green algae), produce toxins that can poison humans, pets, and wildlife.

Water Quality Issues: Blooms can discolor water, produce foul odors, and make water unsafe for drinking or recreation.

Economic Impact: Fisheries, tourism, and water treatment costs increase due to blooms.

Health Impacts of Algal Blooms: Ingesting contaminated water or seafood results in liver and neurological damage, diarrhea, vomiting. The contact of skin with these blooms results in rashes and eye irritation. On inhalation of red tide toxins increase the respiratory issues, asthma aggravation.

Effect on Animals and Marine Life: mass death of fish and shell fish will takes place due to oxygen depletion and toxins. Bioaccumulation of toxins leads to poisoning of Birds and Mammals**.** Pets encountered with fatal poisoning from drinking contaminated water.

Prevention and Control of Algal blooms: the formation of algal blooms can be controlled by various methods.

1. **Reducing Nutrient Runoff**: Using less fertilizer, planting vegetation buffers, and improving wastewater treatment.
2. **Monitoring & Early Detection**: Using satellite imagery and water testing to detect blooms early.
3. **Aeration & Chemical Treatments**: In some cases, aeration or algaecides are used to control blooms.

11.7 ALGAL TOXINS

Algal toxins are harmful compounds produced by certain algae, particularly cyanobacteria (blue-green algae) and some marine algae. These toxins can poison humans, animals, and ecosystems when they contaminate water or seafood. The major types of algal toxins, their source and health effects are detailed in Table 11.1.

Algal toxins affect on humans: Intake of algal toxinated food and water causes serious ingestion followed by liver damage, neurotoxic effects, vomiting, and diarrhea in humans. Inhalation of sea spray, red tide aerosols results in respiratory irritation, asthma aggravation. Skin contact to algal toxins while swimming and contact of contaminated water may produce rashes, eye irritation. In case of children, elderly, and individuals with weakened immune systems may face high risk due to algal toxins.

Algal toxins in animals and ecosystems: The presence of algal toxins in aquatic bodies results in fish death and cause oxygen depletion. The intake of algal toxinated food by birds and mammals causes accumulation of toxins in the food chain. Dogs, cattle, and other animals can die from drinking toxic water.

Table 11.1: Major Types of Algal Toxins and Their Effects

Toxin	Algae Type	Health Effects	Sources
Microcystins	*Microcystis, Planktothrix, Anabaena*	Liver damage, tumor promotion, skin irritation	Drinking water, recreational waters
Anatoxins	*Anabaena, Aphanizomenon*	Neurotoxicity, paralysis, respiratory failure	Contaminated water
Cylindrospermopsins	Cyanobacteria	Liver and kidney toxicity	Drinking water, irrigation
Saxitoxins	Marine dinoflagellates and cyanobacteria	Paralysis, respiratory failure, death	Contaminated shellfish
Brevetoxins	*Karenia brevis*	Neurotoxicity, respiratory irritation	Shellfish, aerosols
Domoic Acid	*Pseudo-nitzschia*	Memory loss, seizures, brain damage	Contaminated shellfish, fish
Ciguatoxins	Marine dinoflagellates	Neurological symptoms, temperature reversal sensation	Reef fish

Testing and mitigation strategies for algal toxins

Detecting and controlling algal toxins is crucial for protecting public health, ecosystems, and drinking water supplies. Below are key testing methods and mitigation strategies for algal toxins.

1. Testing Methods for Algal Toxins

A. Water Testing

Regular monitoring of water sources helps detect harmful algae and toxins. Common testing methods include microscopy, ELISA (Enzyme-Linked Immunosorbent Assay), HPLC (High-Performance Liquid Chromatography), Mass Spectrometry (LC-MS/MS) and Field Test Kits (Strip Tests). Many water treatment facilities use a combination of ELISA and mass spectrometry for accurate toxin detection.

B. Seafood Testing

Sea food testing is of two types, 1.Mouse Bioassay: it is a Traditional method for shellfish toxin detection, but being replaced due to ethical concerns. 2. Chemical Analysis (LC-MS, HPLC): It is a modern method for testing shellfish and fish for toxins like saxitoxins and domoic acid.

2. Mitigation Strategies for Algal Toxins

i. Preventing Algal Blooms: Since toxins come from harmful algal blooms (HABs), reducing bloom formation is the key step. It includes reduce nutrient runoff by limiting fertilizer use, improve waste water treatment through buffer zones, plant vegetation near water bodies to absorb excess nutrients, use sustainable farming and erosion control and use satellite imagery and water sensors to monitor and predict blooms.

ii. **Removing Toxins from Water:** If toxins are already present, treatment methods must be used (Table 11.2). Intake of boiling water does not destroy algal toxins and may even concentrate them.

Table-11.2: Removing methods of algal toxins

Method	Effectiveness	Usage
Activated Carbon Filtration	Effective for microcystins, cylindrospermopsins	Used in drinking water treatment
Reverse Osmosis	Removes most algal toxins	Costly but effective for household systems
Chlorination and Ozonation	Kills algae but may not destroy all toxins	Requires proper dosing
Ultrafiltration	Removes algae and large toxin molecules	Used in advanced water treatment

iii. Controlling algae in water bodies: Algae growth can be controlled by **1**. Aeration and Mixing: It prevents stagnant conditions where algae thrive. **2**. Biological Control: Use algae-eating fish (e.g., grass carp) or beneficial bacteria. **3.** Algaecides: spraying of Copper Sulfate) may effective in controlling algal growth but may lead to toxin release when algae die.

Emergency responses to algal toxin contamination: in times of algal toxin emergency the following steps has to be taken.

Drinking water advisory steps:

1. **Issue public warnings**: Restrict water use and consumption.
2. **Shut down water intakes:** Prevent further contamination.
3. **Use advanced filtration:** Apply activated carbon or reverse osmosis in treatment plants.
4. **Monitor and retest:** Ensure toxins are fully removed before resuming supply.

Recreational water guidelines:

1. **Microcystins safe limit:** < 4 µg/L for swimming (EPA standard).
2. **Avoid discolored or Foamy water:** Blooms often appear green, blue, or red.
3. **Keep pets and livestock away:** Dogs are especially vulnerable.

Monitoring and prevention of algal toxins

Water Safety Measures: Water testing for microcystins and cylindrospermopsins. Activated carbon and advanced filtration for drinking water. Avoid swimming in discolored or foul-smelling water.

Seafood Safety: Monitoring of shellfish and fish in affected areas. Cooking does not destroy algal toxins, and contaminated seafood should be avoided.

11.8 SUMMARY

Algae hold significant economic importance across diverse industries due to their versatile applications and sustainable nature. In the food sector, species like *Porphyra* (nori) and Chlorella are consumed directly, while extracts such as agar, carrageenan, and alginate serve as stabilizers and thickeners in processed foods, cosmetics, and pharmaceuticals. Algae also contribute to renewable energy through biofuel production, offering eco-friendly alternatives to fossil fuels as biodiesel, bioethanol, or biogas. In agriculture, they enhance soil fertility as biofertilizers, reducing reliance on synthetic chemicals. Additionally, algae are vital in biotechnology for producing high value compounds like omega-3 fatty acids, antioxidants, and pigments used in nutraceuticals and pharmaceuticals. Their role in environmental remediation absorbing CO_2, treating wastewater, and mitigating pollution provides cost-effective solutions for industries and governments. As global demand for sustainable resources grows, algae emerge as a critical asset, driving innovation and economic growth in green industries.

Single cell protein (SCP) refers to protein derived from microorganisms such as bacteria, yeast, fungi, or algae, cultivated under controlled conditions to serve as an alternative protein source. SCP production is efficient, requiring minimal land and utilizing substrates like agricultural waste, methanol, or industrial byproducts, making it a sustainable solution to food security challenges. Rich in essential amino acids, SCP is primarily used in animal feed to reduce reliance on traditional protein sources like soy or fishmeal, while also being explored for human consumption in supplements and meat alternatives. Despite its potential, challenges include high nucleic acid content, which requires processing to avoid health risks, and the need for technological and sensory adaptations to improve acceptability. SCP represents a promising, eco-friendly protein alternative in the face of global population growth and agricultural constraints.

Algal blooms, rapid proliferations of algae in aquatic ecosystems, often result from excess nutrients like nitrogen and phosphorus—commonly from agricultural runoff—combined with warm temperatures and stagnant waters. These blooms, particularly harmful algal blooms (HABs), produce potent toxins such as microcystins, which damage liver function, and saxitoxins, which impair nervous systems. These toxins threaten aquatic life, causing mass fish die-offs and contaminating water supplies, thereby endangering human health through consumption or exposure. Additionally, HABs deplete oxygen levels, creating dead zones that devastate marine habitats. Economically, they disrupt fisheries, tourism, and healthcare systems, prompting costly monitoring and mitigation efforts. Addressing nutrient pollution and enhancing water management are critical to curbing these ecologically and socially damaging events.

11.9 TECHNICAL TERMS

Agar agar, Algin, Algal blooms, Biofertilizer, Carrageenin, Cyanophage, AlgalToxin.

11.10 SELF ASSESSMENT QUESTIONS

Q.1 Give a detailed note on commercial aspects of algae.
Q.2 Describe the economic importance of algae.
Q.3 Explain the role of algae in making new world drugs.
Q.4 Describe the Algal blooms and their role in ecological aspects.
Q.5 Explain the algal toxins, their testing methods and remedies for controlling algal toxins.

11.11 SUGGESTED READINGS

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LESSON – 12

GENERAL CHARACTERS AND NUTRITION OF FUNGI

OBJECTIVE OF THE LESSON

Students are able to know the rich diversity among fungal general characteristics and mode of nutrition in fungi.

STRUCTURE OF THE LESSON

12.1 INTRODUCTION

Fungi represent a vast and varied category within the plant kingdom. The term 'fungus' is derived from Latin, meaning mushroom. Fungi are characterized as achlorophyllous and heterotrophic thallophytes. Due to their similarities with algae in several respects, they are classified under the group Thallophyta. The scientific discipline dedicated to the study of fungi is referred to as mycology (from Greek, mykes - mushroom and logos - study), and those who specialize in this field are known as mycologists. Globally, it is estimated that there are between 50,000 and 100,000 recognized species of fungi. Currently, approximately 5,100 genera and 50,000 species of fungi have been identified, a figure that continues to grow as research progresses worldwide. These fungi thrive in a wide range of environments and exhibit significant diversity in their forms, structures, physiological functions, and reproduction. The primary structure of these organisms consists of hyphae, which collectively form the mycelium, with exceptions in certain cases, mycelium is entirely absent E.g.: Synchytrium or the organism is unicellular E.g. Saccharomyces species. Their cell walls are not composed of true cellulose; instead, they are made of chitin or fungal cellulose. Fungi are unable to produce their own food and most of them are saprophytic, parasitic, or symbiotic. Their primary storage forms of energy are glycogen. Reproduction occurs through vegetative, asexual, and sexual means. P. A. Micheli known as Father of Mycology, whereas E. J. Butler refers to as the Father of Indian Mycology.

Fungi obtain nutrients through heterotrophic absorption, meaning they secrete digestive enzymes into their surroundings to break down complex organic matter into simpler molecules, which they absorb. They exhibit diverse nutritional modes, including saprophytic (decomposing dead

organic material), parasitism (extracting nutrients from living hosts, sometimes causing disease), and mutualism (forming symbiotic relationships, such as mycorrhizae with plant roots or lichens with algae). Unlike plants, fungi lack chlorophyll and cannot perform photosynthesis, relying entirely on external organic sources for sustenance. Their ability to decompose complex substances like cellulose and lignin makes them essential for nutrient cycling in ecosystems.

Occurrence and Distribution

Fungi exhibit a remarkable degree of cosmopolitanism and diversity, thriving in nearly every habitat. They prefer to grow in warm and humid places. They can be classified into various categories, with some existing in terrestrial environments, others in the air, and some inhabiting both freshwater and marine ecosystems. Additionally, certain fungal species can be found in an epiphytic state on algae and various aquatic plants, while others decompose dead organic matter in water. Some fungi reside beneath the earth's surface, displaying a sub-terrestrial lifestyle, and a select few act as endophytes within the leaves and stems of healthy plants. Additionally, numerous fungal species are parasitic, infecting a wide range of plants, animals, and humans.

12.2 THALLUS ORGANIZATION

The fungal kingdom exhibits several distinct characteristics that differentiate it from the plant, animal, and other biological kingdoms. Except some unicellular forms (e.g. yeasts, Synchytrium), the fungal body is a thallus called mycelium. The mycelium is an interwoven mass of thread-like hyphae (Sing. hypha). Hyphae may be septate (with cross wall) and aseptate (without cross wall). Some fungi are dimorphic that found as both unicellular and mycelial forms e.g. Candida albicans. The thallus may be two types: 1. Unicellular and 2. Filamentous.

1. Unicellular thallus: In some of the lower fungi, thallus is more or less a spherical, single celled structure. At the time of reproduction it becomes a reproductive unit. Such fungi are called as holocarpic fungi. In the unicellular holocarpic forms, the mycelium is absent e.g. Synchytrium. Some holocarpic fungi (e.g., yeast) producing bud cells in succession and these remain attached to one another in a chain. Such a chain of bud cells is referred to as pseudomycelium. Different unicellular forms of fungi are as follows.

Yeast: Yeast is of wide occurrence; is found on sugary surface of ripened fruits and can be easily grown in any sugar solution. Individual cells remain attached to each other forming a chain. Fine structure of a yeast cell resembles with that of a eukaryotic cell. The cell has a well-defined nucleus, endoplasmic reticulum, mitochondria and other organelles along with a large area of the cell occupied with a vacuole.

Slime molds: Slime moulds are usually multicellular, sometimes unicellular (multinucleate) forms are also seen. However, these are not considered as true fungi. During the course of their life cycle, these organisms show protozoan-like (unicellular and multinucleate) or fungus-like stages (multicellular). The slime moulds are of two types:

(a) Cellular type: Dictyostelium discoideum referred to be as myxamoeba. It depends on bacteria during vegetative stage and divides via binary fission. Later numerous myxamoeba aggregate to form a single multinucleate structure known as a slug, while the individual cells are maintain their distinct cell membranes. This formation is termed as pseudoplasmodium. Similar

to true fungi, during the reproductive phase, spores are generated within sporangia. Each spore, upon germination, develops into an amoeba-like structure.

(b) Plasmodial type: Echinostelium minutum forms a large mass of multinucleate amoeboid cytoplasm with diploid nuclei during vegetative phase. The individual cells are however not delimited by cell membrane. It feeds on bacteria and encysted myxamoeba. They do not have a definite size or shape. It alters its shape depending upon the substratum. During reproductive phase entire plasmodium takes part in formation of fructification which bears spores. Spores germinate to form flagellated cells which later on develop into plasmodium.

2. Filamentous thallus: In most true fungi, the thallus is filamentous composed of hyphae. Loosely aggregated hyphae are collectively forms a network known as mycelium. Each hypha may vary in shapes and sizes. Branching of hyphae is dichotomous. On the basis of presence or absence of septa the hyphae of mycelical fungi are of two types a) Non-septate hyphae or aseptate hyphae b) Septate hyphae

a) Non-septate or aseptate hyphae: Mycelium contains numerous nuclei, lying in a common mass of cytoplasm, without cross wall in the hyphae, E.g., oomycetes and zygomycetes. Such a condition is known as coenocytic. However, septa may be laid down at the time of formation of reproductive organs to delimit them from the rest of the vegetative hyphae, therefore called as Pseudosepta. E.g., Allomyces.

b) Septate hyphae: Hyphae are septate and hyphal segments may contain one, two or more nuclei. E.g., Ascomycotina, Basidiomycotina and Deuteromycotina. There are two types of septa i) Primary septa ii) Adventious septa

i) Primary septa: Primary septa are formed in association with mitotic or meiotic nuclear division, and they separate the daughter nuclei. Ascomycotina, Basidiomycotina and their asexual states

ii) Adventitious septa: Adventitious septa are formed in the absence of mitosis or meiosis and occur especially in association with change in the local concentration of cytoplasm. E.g.: lower groups of fungi as Mastigomycotina and Zygomycotina.

In Ascomycetes, the continuity of cytoplasm is preserved through a small, simple pore located at the center of the septa. In Basidiomycetes, with the exception of rusts and smuts, perforated septa are also present, albeit with a slight modification characterized by a barrel shaped inflation featuring a hemispherical perforated membrane on either side of the opening, referred to as the dolipore septum. Fungal mycelium is classified as homokaryotic when the individual cells of the septate hyphae possess genetically identical nuclei. Conversely, some fungal mycelium contains nuclei of varying genotypes, which may result from mutations or the anastomosis of hyphae; these are termed as heterokaryotic. Members of Basidiomycetes can exhibit either two genetically distinct nuclei (dikaryotic) or a single haploid nucleus that is genetically identical within each segment (monokaryotic).

Aggregations of fungal hyphae: At certain stages in life history of all fungi they show various degrees of hyphal aggregation ranging from loosely to compactly woven tissues. All such

organized fungal tissues are known as plectenchyma. The three general types of plectenchyma are:

a. **Prosenchyma/Prosoplectenchyma:** Hyphae are loosely interwoven lying more or less parallel to each other.
b. **Pseudoparenchyma/paraplectenchyma:** Hyphae are compactly interwoven looking like a parenchyma in cross-section.
c. **Pseudosclerenchyma:** It consists of closely packed, thick-walled and dark cells

Plectenchyma forms various types of vegetative and reproductive structures such as mycelial strands, mycorrhiza, rhizomorph, stroma, sclerotia and sporophore.

Mycelial strands: These structures are found in Basidiomycetes and some Deuteromycetes. They consist of parallel and relatively simple hyphae. A mycelial strand forms around one or more leading hyphae, which grow from the edge of the thallus. These leading hyphae become surrounded by their own branching and intertwining parts, creating a cord that is 1-2 mm thick and several centimeters long. Mycelial strands help to transport materials and allow the fungus to reach new food sources from an existing base.

Mycorrhiza: It is a symbiotic relationship between fungal threads (Agaricales) and the roots of plants. The tips of roots in both coniferous and deciduous plants often consist of multiple layers of fungal cells. The fungal mycelium grows into the soil and then into the root's cortical cells, creating a structure known as the 'Hartig network.' This extended fungal mycelium takes over some of the root's functions, helping to absorb more minerals from the soil. Roots that have this mycorrhizal network perform better than those that do not.

Rhizomorph (Gr. rhiza = root + morphe = shape): These are highly differentiated root like hyphal aggregations which have a well developed apical meristem, a central core (thin-walled, elongated cells) and a rind (smaller, thick-walled highly pigmented cells). These are produced by Armillaria mellea, a tree and shrub parasite. Rhizomorphs helps the fungus in spreading from one root system to another.

Stroma: This is a small cluster of hyphae that looks like a cushion or mattress where fruiting bodies develop. These structures are found in groups like Deuteromycetes, Basidiomycetes, and Ascomycetes, appearing as different types of ascocarps, pycnidia, basidiocarps, acervuli, synnemata, and sporodochia.

Sclerotium (pl. **Sclerotia, Gr. Skleros=haid):** A tough resting structure is created by the clumping of somatic hyphae. These structures can be round, long, or flat, and their size, shape, and color are unique feature of specific species. Each Sclerotium germinates into a mycelium, on return of favourable condition e.g., Penicillium.

Microsclerotia (Macrophomina phaseoli): Most sclerotia are less than 100 micrometers wide, with many not exceeding 2 cm. In contrast, Polyporus myllittae has sclerotia that can be more than 25 cm wide and weigh several kilograms. These structures store nutrients and help the fungus endure harsh conditions by functioning as a propagule.

Sporophores: These structures produce spores and are typically upright and above ground. They can be branched, like in Peronospora, or unbranched, like in Albugo. They carry sporangia in Albugo and conidia in Peronospora. Structures that hold sporangia are called sporangiophores, while those that

hold conidia are called conidiophores. Sporophores often appear in clusters and can create formations like pycnia, hymenia, sporodochia, and acervuli.

Rhizoids: A rhizoid is a small, root-like branch of the thallus that usually grows in clusters at the bottom. They help with anchoring and absorbing nutrients, as seen in organisms like Rhizophydium and Rhizopus.

Appressoria (Sing. appressorium): It is a terminal, swollen, sticky structure made of infecting hyphae that sticks to the host or other surfaces, aiding in the infection process. This structure is formed by certain parasitic fungi like powdery mildews and rust.

Haustoria (Sing. haustorium): Haustoria are specialized structures that arise from hyphae, primarily serving the purpose of nutrient absorption. These organs are typical of obligate parasitic organisms. Their morphology can differ significantly, exhibiting various froms like button-shaped, elongated, finger-like, or branched. Additionally, haustoria produce specific enzymes that facilitate the hydrolysis of proteins and carbohydrates present in the host plant.

Hyphal traps (Snares): The predacious fungi produce sticky filaments or a network of loops called hyphal traps or snares. They use these to catch nematodes.

Stromata: These are small body structures similar to mattresses. Fruits usually develop on or inside them.

12.3 ULTRA-STRUCTURE AND COMPOSITION OF FUNGAL CELLS

Unicellular yeast as well as the filamentous fungi has a typical eukaryotic cellular organization (Figure 12.1). As other non-photosynthetic organisms, fungi contain all major organelles except chloroplast. The detailed structure of fungal cell is given here under.

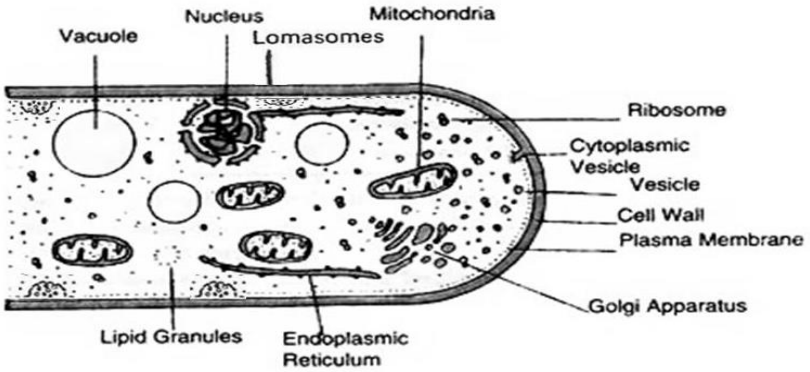

Figure-12.1: Ultra structure of fungal cell (https://tinyurl.com/5fryhz7e)

Cell Wall: Fungal cells, with the exception of slime molds (Myxomycetes), are characterized by a rigid cell wall and various organelles. The composition of the cell wall varies among different fungal taxa. Chemical analyses indicate that the cell wall is primarily composed of 80-90% polysaccharides (glycans), with the remainder consisting of proteins (such as glycoproteins and glycalyx) and lipids (including phospholipids and glycolipids) as illustrated in Figure 12.2. The cell walls typically contain chitin (a polymer of N-acetyl glucosamine), cellulose (a polymer of

D-glucose), or other glucans, which are organized into fibrils that form distinct layers. Most fungi do not possess cellulose in their cell walls, with the notable exception of Oomycetes; however, chitin and cellulose are often found together in certain species, such as Ceratocystis and Rhizidiomyces, which contain a variant of chitin referred to as fungus cellulose. The structural formulas for the repeating units of cellulose and chitin are presented in Figure 12.3.

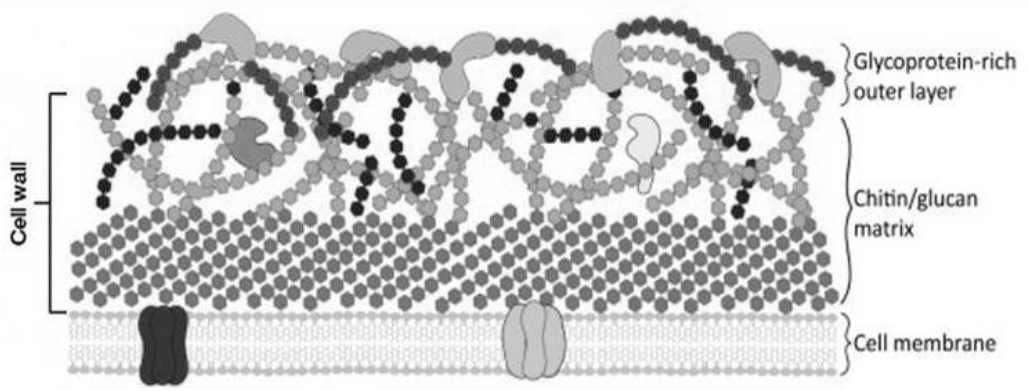

Figure-12.2: Structure of bacterial cell wall (https://tinyurl.com/4kmmatdw)

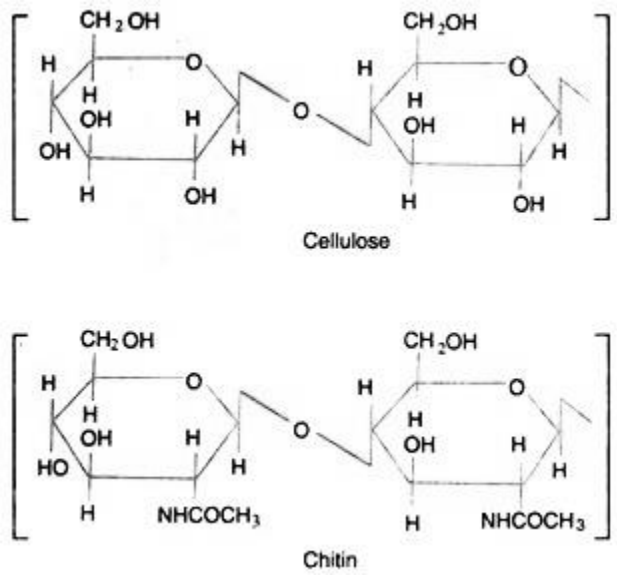

Figure-12.3: Structures of cellulose and chitin (https://tinyurl.com/zawhcjyy)

Chitin constitutes the principal component of cell walls; however, cellulose is also present in Oomycetes, accompanied by glucans. In addition to cellulose, their cell walls incorporate an amino acid and a hydroxy-protein. Furthermore, various proteins and enzymes are associated with these cell walls. In the genera Peronospora and Saprolegnia, true cellulose is identified, whereas Phytophthora and Pythium are characterized by the absence of cellulose and a higher concentration of glucans. Certain fungi have been documented to possess chitin within their cell walls. The predominant constituents of cell walls in Zygomycetes, Ascomycetes, and

Basidiomycetes are chitin; however, yeasts and some members of Hemiascomycetidae lack chitin, with their cell walls composed of micro-fibrils of mannans and β-glucan (Table 12.1).

Table 12.1 Taxonomy of fungal cell walls

Taxonomic grouping	Fibrillar polymers	Matrix polymers	Perforate septa present or absent
Oomycetes	β(1,3)-, β(1,6)-Glucan Cellulose	Glucan	Absent
Chytridomycetes	Chitin; glucan	Glucan	Absent
Zygomycetes	Chitin; chitosan	Polyglucuronic acid; glucuronomannoproteins	Absent
Basidiomycetes	Chitin; β(1,3)-, β(1,6)-glucans	α(1,3)-Glucan; xylomannoproteins	Present (mostly Dolipore)
Ascomycetes/ Deuteromycetes	Chitin; β(1,3)-, β(1,6)-glucans	α(1,3)-Glucan; galactomannoproteins	Present (mostly simple with large central pore)

Plasma Membrane (Plasma lemma/Cell Membrane): The plasma membrane, which encases the cytoplasm, is situated just beyond the cell wall. This membrane exhibits semipermeable properties and shares structural and functional characteristics with prokaryotic membranes. Notably, specialized organelles are present on the surface of the plasma membrane. It has the capacity to invaginate, forming pouch-like structures that contain granular or vesicular substances. Moore and McAlear (1962) designated these formations as lomasomes. Lomasomes arise from various membrane configurations external to the plasma membrane, known as plasmalemmasomes. These plasmalemmasomes may facilitate the regulation of material transport into and out of the cell and could also be involved in the utilization of bicarbonate during the process of photosynthesis.

Cytoplasm: Cytoplasm is a colorless substance that contains sap-filled vacuoles. The inclusions found within the cytoplasm are typically non-functional, dead, E.g.: glycogen, oil droplets, pigments, and secretory granules. With the exception of chloroplasts, most organelles such as the endoplasmic reticulum, mitochondria, ribosomes, Golgi apparatus, microbodies, filasomes, vacuoles, and multivesicular bodies (MVBs) are located within the fungal cytoplasm. Additionally, certain fungi possess Woronin bodies, which are linked to septal pores. Lomasomes can also be found situated between the plasma membrane and the cell wall.

Endoplasmic Reticulum: The structure consists of a network of microtubules interspersed with small granules. In the majority of fungi, it exhibits a highly vesicular nature. When compared to the cells of green plants, it appears loose and irregular. In multinucleate hyphae, the nuclei can be linked by endoplasmic reticulum.

Mitochondria: Mitochondria, which are numerous small structures ranging from spherical to elongated shapes, are found throughout the cytoplasm. These organelles are encased in a double membrane. The inner membrane features infoldings that create parallel flat plates of irregular

tubules, referred to as cristae. Mitochondria contain their own mitochondrial DNA (mt-DNA), which exists as circular double helical molecules that lack histones. Additionally, mitochondria possess their own machinery for the transcription and translation of organelle-specific DNA.

Golgi Apparatus/Dictyosomes: In fungal cells, the Golgi apparatus is infrequently found, with the exception of Oomycetes (such as Pythium) and non-fungal eukaryotic cells. In these organisms, the Golgi apparatus is characterized by stacks of folded membranes, play vital role in secretion. Notably, in Saccharomyces cells, one can observe a Golgi apparatus composed of three flattened sacs.

Vacuoles: Vacuoles are present in the mature cells of hyphae, while the tips of young hyphae do not contain vacuoles. As the hyphae age, the vacuoles merge together. These vacuoles are encased by a membrane referred to as the tonoplast.

Septum: A cross wall serves to separate adjacent cells in fungal structures (Figure 12.4). There are primarily three types of septa observed in fungal cells: (a) Complete septa, which are devoid of pores and are infrequently found in vegetative hyphae (b) Perforated septa, which possess a pore allowing the free passage of cytoplasmic organelles, such as mitochondria and nuclei, commonly seen in Ascomycetes and Deuteromycetes, and (c) Dolipore septa, named after the Latin word "dolium," meaning a large jar, which are characteristic of Basidiomycetes and exhibit greater complexity. The central pore of these septa is encircled by a curved flange of wall material, often thickened to create a barrel-shaped cylindrical structure. Additionally, these septa are frequently covered by the perforated endoplasmic reticulum, with the central pore cap referred to as the parthenosome.

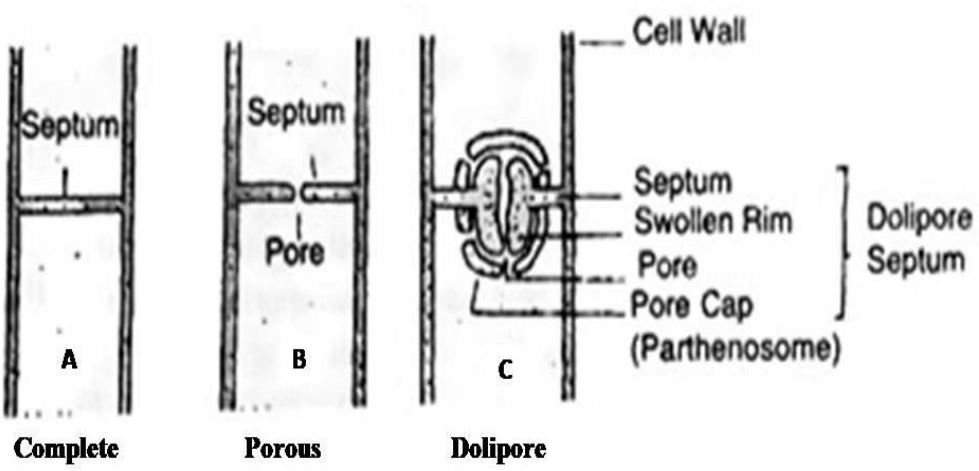

Figure-12.4: Various types of septa in fungi (https://tinyurl.com/5fryhz7e)

Cytoplasmic Inclusions: The cytoplasm is composed of a range of inclusions, including lipid droplets, glycogen, trehalose, proteinaceous substances, and volutin. Glycogen is stored within the vacuoles. The cytoplasm also secretes various metabolites, including enzymes and organic acids. In fully developed cells, there is a significant presence of lipids and glycogen.

Nucleus: The cytoplasm may contain one or more spherical nuclei, each measuring approximately 1-3 micrometers in diameter. A nucleus is characterized by a bilayered, porous nuclear envelope that surrounds the chromosomes and the nucleolus. Chromosomes are composed of DNA along with several fundamental proteins known as histones. The DNA content undergoes continuous changes in relation to cell growth. Nuclear pores facilitate the exchange of materials between the cytoplasm and the nucleus.

12.4 FUNGAL NUTRITION

Unlike green plants, fungi meet their nutritional requirements by assimilating preformed organic matter and carbohydrates are the preferred nutrient source. Fungi are achlorophyllas, heterotrophic eukaryotic thallophytes. Fungi can readily absorb and metabolize a variety of soluble carbohydrates, such as glucose, xylose, sucrose, and fructose, but are also characteristically well equipped to use insoluble carbohydrates like starches, cellulose, hemicelluloses, and lignin.

Nutritional requirements of Fungi

Fungi are heterotrophic in nutrition. They are chlorophyll lacking organisms, hence cannot manufacture carbohydrates. Fungi mostly dependent on dead or living organic matter for their energy requirements. All fungi are chemoheterotrophic and can synthesize the organic compounds from pre-existing organic sources using chemical reactions. Since their protoplasm is protected by a rigid wall, fungi must obtain their nutrients by the process of absorption. Small molecules (e.g. simple sugars, amino acids) in solution can be absorbed directly across the fungal wall and plasma membrane. Larger, more complex molecules (e.g. polymers such as polysaccharides and proteins) broken down into smaller molecules, and absorbed. This degradation takes place outside the fungal cell or hypha and is achieved by enzymes which are either released through or are bound to the fungal wall. Because these enzymes act outside the cell they are called Extracellular enzymes.

Essential Elements and their sources

Fungi require various elements as food source in extremely micro and macro elements. These elements include C, O, H, N, P, K, Mg, S, P, Mn, Cu, Mo, Fe, Zn and Calcium. The macro elements are body builders and provide energy for metabolic processes. The organic substances usually utilized by fungi are very varied in nature. The carbohydrates are needed for building up the body and also as a source of energy. In a typical fungus, 50% of the dry weight is carbon of the carbohydrate source of carbon, most fungi use simple sugars. Glucose is suitable for almost all fungi and next in preference are the fructose and Sucrose. The polysaccharides, starch and cellulose are utilized by a fewer fungi which can synthesize the appropriate hydrolytic enzymes. Less commonly used sugars are the hexose sugars and some pentoses. Mannitol is equivalent to glucose for many fungi. Maltose which occurs in nature as a byproduct of starch hydrolysis is utilized by many fungi. Basidiomycetes include most of the lignin-utilizing fungi. Some fungi are able to make good growth on fats as the only source of carbon. Proteins, lipids some organic acids and higher alcohols are utilized by some fungi as a sole energy source of growth, however, is always better on a substance containing a suitable carbohydrate. Besides carbon, fungi require nitrogen. Fungi require nitrogen through both organic and inorganic materials. In nature, fungi decompose proteins and peptide or an amino acid to obtain their supply of nitrogen. The

members of Saprolegniaceae and Blastocladiales grow only with organic nitrogen such as amino acid. In pure cultures amino acids, peptides, or peptones gelatin, casein and egg albumin can serve as sources of organic nitrogen for building up protoplasm. Urea is also considered as an utilizable nitrogen source for some fungi. Many fungi, however, obtain nitrogen from inorganic sources. A number of fungi are known which use both nitrate and ammonium salts (Example: Absidia sp., Mucor hiemalis, Lenzites trabea and Marasmius sp.).

Fewer fungi are able to utilize nitrate salts. Organic sources of nitrogen can also serve as sources of carbon. Soil inhabiting Rhodotorula and yeast-like Pullularia pullans fix atmospheric nitrogen. Hydrogen and oxygen are supplied in the form of water which is the major constituent of fungus mycelium forming about 85- 90% of the entire weight. The chief among the inorganic nutrients which the fungi require in fairly large amounts for their mineral nutrition are sulphur, phosphorus, potassium and macronutrients the fungi obtain from simple inorganic salts or sources such as sulphates for sulphur, and phosphates for phosphorus. Some fungi are reported to require only minute traces of iron, zinc, copper, manganese and cobalt and molybdenum in anionic forms. Calcium is not known to be needed by the fungi in general. Some, however, require it as a micronutrient. Some fungi are reported to require only minute traces of iron, zinc, copper, manganese and cobalt and molybdenum. These trace elements or micronutrients are considered essential of growth. The form in which the major and the minor metallic element requirements are utilised is the anion. Fungi store excess food in the form of glycogen or lipids. Fungi utilize the vitamins or growth factors in minute amounts. The important fungal vitamins, which may function in enzyme systems include thiamine (B1), biotin, pyridoxine (B6) and riboflavin (B2). A few fungi also need nicotinic acid and pantothenic acid. The vast majority, however, require thiamine (B1). A few fungi also need nicotinic acid and pantothenic acid.

Mode of Nutrition in Fungi

On the basis of mode of nutrition, fungi are classified into four groups namely 1. Saprophytes 2. Parasites 3. Symbionts 4. Predaceous.

1. Saprophytic Fungi: Saprophytic fungi obtain their nutrition from dead organic matter. It may be both animal and plant origin. The vegetative phase of these fungi directly absorbs nutrition required for their growth. Some species bear special structures for absorption of nutrition called rhizoids. These fungi mainly produce exo-enzymes for release of simple organic matter. They may be of two types.

i. **Ectophytic saprophytes:** Grow on the surface of organic matter.
ii. **Endophytic saprophytes:** Grow inside the organic matter E.g. Saprolegnia, Mucor, Rhizopus, Aspergillus, Penicillium, Agaricus etc.

2. Parasitic fungi: The parasitic fungi absorb their food material from the living tissues of the hosts on which they parasitize. Such parasitic fungi are quite harmful to their hosts and cause many serious diseases (Figure 12.5). The living organisms on which fungi grow are called host. The growing fungi are harmful to the host as they develop disease conditions in their host. Such relationship is known as parasitism. The parasitic fungi absorb their food from the hosts in different ways either internal or external. On the basis of location of parasitic fungi in their host they are classified into two groups.

i. Ectoparasitic: Fungi live on outer surface of host (E.g. Erysiphe)

ii. Endoparasitic: Fungi grow inside the host tissue (E.g. Fusarium)

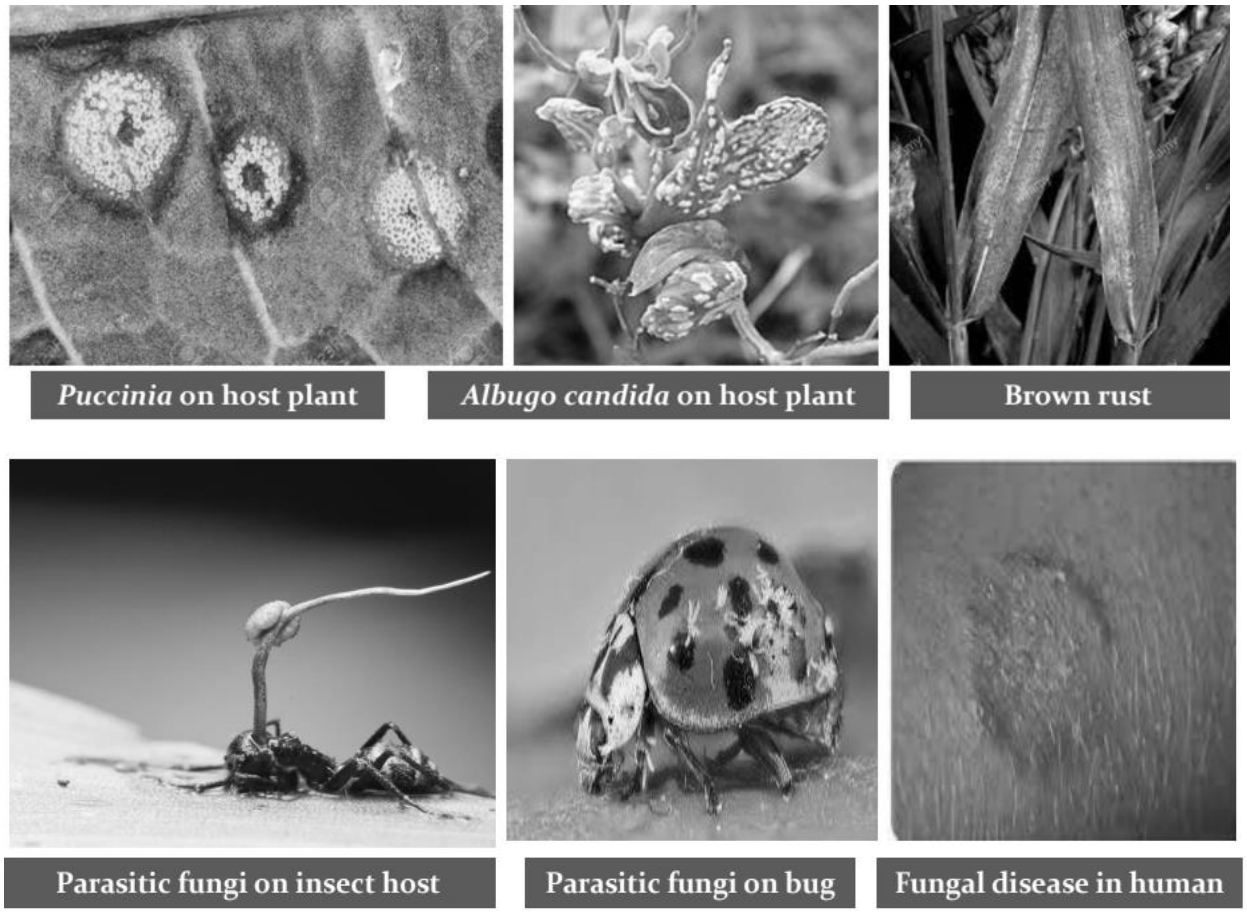

Figure-12.5: Fungal infections on various plants and animals

In ectoparasitic type of fungi cushion-like appressoria develop on the surface of the host and from each appressorium a peg-like structure develops which penetrates the host epidermal cell giving rise to a branched or unbranched absorbing organ called the haustorium (Figure 12.6). Its size and shape varies in different fungal groups. It may be round, knob like, club like or branched E.g. Erysiphae, Phytophthora, Albugo. These fungi cause the great losses to the human beings directly or indirectly. The rusts, smuts, bunts, mildews and many other plant diseases are important examples of fungal diseases of crops. The haustoria may also develop from the mycelium of endoparasites. The haustoria vary in their shapes. They may be small, rounded, and button-like as in Albugo, branched and convolute as in Peronospora and highly branched as in Erysiphe. In the case of rusts and mildews the mycelium remains confined in the pustules and not in the whole body of the plant. This type of fungus is called the localized fungus. When the mycelium prevails in the whole of the plant it is said to be systemic fungus, e.g., smuts. When the mycelium is confined to the intercellular spaces it is called intercellular mycelium and in other cases the mycelium penetrates the host tissue and said to be intracellular.

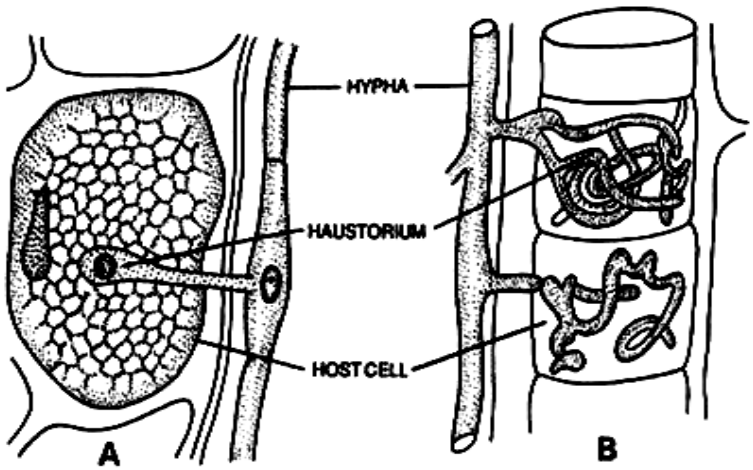

Figure-12 .6: (A) Elongated capitates haustorium (B) Branched or digitate haustorium

Based on their mode of infection, fungi are of three types.

i. **Obligate parasites:** essentially require living host, not able to live on dead organic matter E.g. Puccinia, Albugo
ii. **Facultative Saprophytes:** These are parasites but can live on dead organic matter when specific host is not available E.g. Taphrina.
iii. **Facultative parasites:** These are usually saprophytes but under certain conditions they parasitize living host E.g. Fusarium, Phythium

3. Symbionts: These fungi grow on or with living organisms but both of them are mutually benefitted E.g. Lichen and Mycorrhiza. Lichens are symbiotic association of algae and fungi. Mycorrhiza are symbiotic association of fungi and roots of higher plants. It may be ecto or endo mycorrization in location.

Lichen thallus: The intervention of two organisms form a single composite thallus plant which different from either of the partners in form and habit. Both live together and are beneficial to each other. The algal partner synthesizes the organic food and the fungal partner is responsible for the absorption of inorganic nutrients and water.

Mycorrhiza (pl. Mycorrhizae or mycorrhizas): It is defined as the symbiotic association between the hypha of certain fungi and roots of plants. Certain fungi develop in the roots of higher plants and the mycorrhiza are developed. Here fungi absorb their food from the roots and in response are beneficial to the plants. The mycorrhiza may be three types. a) Ectomycorhiza b) Endomycorhiza c) Ectoendomycorhiza.

a) Ectomycorrhiza: In this case fungal hyphae form a complete envelope around the root tip and also penetrate and extend into the first few cortical layers to form an intercellular network of hyphae known as the Hartig net (Figure 12.7). The hyphal strands that extend into the substrate from the envelope absorb water and nutrients from the soil and pass them on to the roots of the plant through the Hartig's net. The presence of the fungus thus increases root absorption. In return the fungus receives food and shelter.

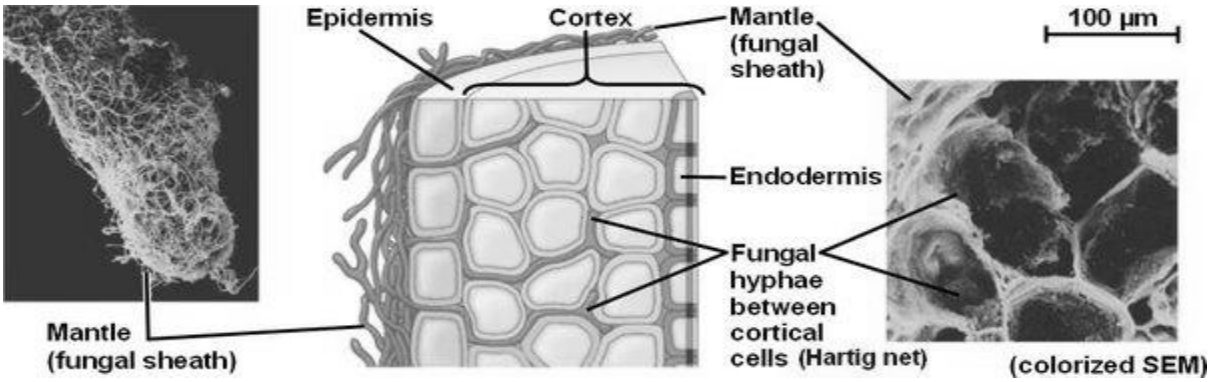

Figure-12.7: Ectomycorhiza of fungi (https://tinyurl.com/mutb9fau)

b) Endomycorrhiza: The fungal hyphae, in this case, penetrate root hairs, epidermis and reach the cortex where they grow intracellularly forming fungal arbuscules in the cortical cells (Figure 12.8). A portion of the mycelium lives in the soil but it forms no dense hyphal growth.

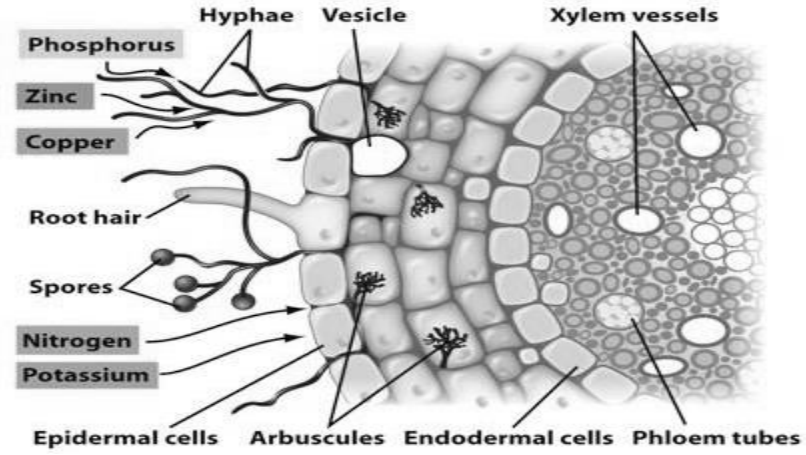

Figure-12.8: Endimycorhiza of fungi (https://tinyurl.com/2s3vyz5v)

c) Ectoendomycorrhiza: It is a combination of the two. The fungal hyphae form a sheath at the surface of the root. Within the root, they grow intercellularly and intracellulary.

4. Predacious Fungi: There are many animal trapping fungi which have developed ingenious mechanisms for capturing small animals such as eel worms, rotifers or protozoa. The fungi possess special hyphal traps called snares which capture small animals like amoeba and nematodes. These fungi usually inhabit in the soil. They possess rapid constructing hyphal traps and penetrating haustoria to fetch nutrition from their prey. Some predacious fungi secrete a sticky substance on the surface of their hyphae to which a passing small animal adheres. Haustorium like hyphae then grows into the body of the animal and absorbs food, finally animals die. E.g. Arthrobotrys, Dactylaria.

Mechanism of Nutrition: The whole mycelium may have the power to absorb these nutrients or this task may be assigned to special portions of the mycelium. In saprophytic fungi, the hyphae (Mucor mucedo) or rhizodial hyphae (Rhizopus stolonifer) come in intimate contact with

nutrients in the substratum and absorb soluble smaller molecules such sugars and amino acids. Insoluble complex substances such as proteins, lipids etc. are first broken into soluble monomers (digested) by secreting extra-cellular enzymes and then absorbed. The mycelium of the parasites is rarely ectophytic but frequently it grows inside the host. The hyphae either ramify in the intercellular space between the host cells

or penetrate into the host cells. The intercellular hyphae of some highly specialized (obligate) plant parasites give out slender lateral outgrowths.

12.5 SUMMARY

Fungi are a diverse group of eukaryotic organisms that include yeasts, molds, and mushrooms. They belong to the kingdom Fungi and play crucial roles in ecosystems as decomposers, symbionts, and even pathogens. Their unique characteristics distinguish them from plants, animals, and bacteria. Fungi are eukaryotic organisms with a well-defined nucleus and membrane-bound organelles. Their cell walls are primarily composed of chitin, which provides structural support, distinguishing them from plants that have cellulose-based cell walls. Fungi are heterotrophic organisms, meaning they obtain their nutrients from external sources. They exhibit absorptive nutrition by secreting digestive enzymes into their environment and absorbing the breakdown products. They can be saprophytic (decomposers), parasitic (feeding on living hosts), or mutualistic (engaging in symbiotic relationships). Fungi reproduce both sexually and asexually. Asexual reproduction occurs through spore formation (e.g., conidia or sporangiospores), budding (as in yeasts), or fragmentation of hyphae. Sexual reproduction involves the fusion of specialized reproductive structures, leading to genetic variation. Most fungi grow as multicellular filamentous structures called hyphae, which form a network called mycelium. Some fungi, such as yeasts, exist as unicellular organisms. The hyphae can be septate (divided by cross-walls) or coenocytic (without cross-walls). Fungi are essential decomposers, breaking down organic matter and recycling nutrients in ecosystems. Some form mutualistic associations, such as mycorrhizae with plant roots and lichens with algae or cyanobacteria. Others act as pathogens, causing diseases in plants, animals, and humans. Fungi have various industrial and medical applications. They are used in food production (e.g., yeast in baking and fermentation), antibiotics (e.g., Penicillium producing penicillin), and biotechnology. However, some fungi cause spoilage and diseases, such as rusts, smuts, and mycoses in humans.

Fungi obtain their nutrients through heterotrophic absorption, meaning they rely on organic substances from their environment rather than producing their own food through photosynthesis. Unlike plants, fungi lack chlorophyll and cannot perform photosynthesis, so they derive energy by breaking down organic matter. They achieve this by secreting digestive enzymes into their surroundings, which break down complex molecules like carbohydrates, proteins, and lipids into smaller, absorbable forms. Fungi exhibit different modes of nutrition based on their ecological roles. Saprophytic fungi play a crucial role in decomposition by breaking down dead organic material, such as fallen leaves, wood, and animal remains, recycling essential nutrients back into the ecosystem. Examples of saprophytic fungi include mushrooms, molds, and many species of yeast. Parasitic fungi, on the other hand, extract nutrients from living organisms, often causing diseases in plants, animals, and even humans. They penetrate host tissues using specialized structures called haustoria, which help them absorb nutrients directly from the host cells. Examples of parasitic fungi include rusts, smuts, and the fungal pathogens responsible for

athlete's foot and ringworm. Another category of fungi are mutualistic fungi, which form symbiotic relationships with other organisms for mutual benefit. A well-known example is mycorrhizal fungi, which associate with plant roots, enhancing water and nutrient absorption while receiving carbohydrates from the plant in return. Lichens are another example, where fungi and algae or cyanobacteria live together, with the fungal partner providing structure and moisture while the photosynthetic partner produces food. Fungi use specialized structures such as hyphae and mycelium to maximize nutrient absorption. The extensive network of thread-like hyphae increases surface area, allowing for efficient absorption of nutrients. In some fungi, specialized hyphae called rhizoids anchor them to their substrate, further aiding in nutrient intake.

12.6 TECHNICAL TERMS

Ascomycetes, Basidiomycetes, Deuteromycotina, Appressoria, Arbuscular Mycorrhiza (AM), Hypha, Lichen, Saprophyte, Slime Moulds.

12.7 SELF ASSESSMENT QUESTIONS

Q.1 Describe the general characters of fungi.

Q.2 Explain the modes of nutrition in fungi.

Q.3 Describe the ultra structure of fungal cell.

12.8 SUGGESTED READINGS

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Prof. A. Amruthavalli

LESSON – 13

REPRODUCTION IN FUNGI

OBJECTIVE OF THE LESSON

Students are able to learn the various asexual and sexual methods of reproduction in the different fungal species.

STRUCTURE OF THE LESSON

13.1 INTRODUCTION

Reproduction is the biological process by which organisms produce offspring, ensuring the continuation of their species. Generally, most of the fungi reproduce through either asexual or sexual mode of reproduction. Some fungal species do not go through true sexual reproduction and instead follow **parasexuality**, which offers an important source of genetic variation in the progeny. Fungi that exhibit sexual reproduction can also show parasexuality.

On the basis of involvement of the thallus in the formation of asexual and sexual reproductive organs fungi are categorized as holocarpic and eucarpic. In some fungi for the formation of reproductive structures the entire thallus gets converted into one or more reproductive structures. This ensures that somatic and reproductive phases do not occur together in the same individual. Those fungi which follow this type of pattern are known as **holocarpic** (Gr. holos = whole + karpos = fruit) fungi. However, in majority of the fungi the somatic and reproductive phases occur together in the thallus as only a portion of the thallus gets converted into reproductive structure. The remaining portion of the thallus continues with normal somatic activities. Fungal species which show this type of pattern are called **eucarpic** (eu = good + karpos = fruit) fungi. The eucarpic forms are more differentiated than the holocarpic fungi. Usually, fungi reproduces both asexually and sexually but not at the same time in their life cycle. Asexual reproduction is more important for colonization of a species as it is repeated several times in the life cycle of a species and results in production of large number of individuals, whereas in most of the fungi the sexual stage is produced only once a year. Because of the pleomorphic nature of the fungi, a new terminology was proposed by Hennebert and Weresub (1977) which was widely accepted.

According to this, sexual stage of the fungus is described by the term **teleomorph** while asexual stage is described by the term **anamorph**. While whole fungus with all its forms, facets, either latent or expressed even if reproduces by one method is known as **holomorph**. More recently, these terms are replaced by **meiosporic** fungus (teleomorph) and **mitosporic** fungus (anamorph).

13.2 TYPES OF REPRODUCTION

Asexual reproduction is also known as somatic reproduction and it does not involve karyogamy (Gr. karyon = nut + gamos = marriage). This is the most important type of reproduction in fungi. **Sexual** reproduction, on the contrary, is characterized by union of two compatible nuclei followed by meiosis. This type of reproduction usually takes place only once in the life cycle of the organism and may or may not involve specialized sex cells or organs. This reproduction helps them in adapting themselves to different environmental conditions.

Asexual Reproduction

Asexual reproduction takes place when progeny is formed by a single parent without any nuclear contribution from the second parent. Therefore, genetically the progeny is exact copy of the parent cell or thallus. Asexual reproduction is considered as imperfect state. Asexual reproduction is often defined as non-sexual production of specialized reproductive cells such as spores. Asexual spore is delimited from the thallus and in contrast to the vegetative mycelium they have minimal metabolic turnover, low water content and lack of cytoplasmic movement. The following types of asexual methods of reproduction were observed in fungi.

Fragmentation: Fragmentation results from accidental severing of the mycelium into several small bits or fragments by mechanical injuries. Under favourable condition each fragment further develops into a new mycelium.

Thallospores: In some fungal species, the fragmentation of parent hyphae forms into various spore like structures called thallospores (asexual spore). These thallospores are of two types viz., a) arthrospore and b) chlamydospore.

a) Arthrospore or oidia: The distal end of hyphae breaks up into component cells by close septation and each component cell behaves as an individual spore. They are always formed in basipetal succession that is septation starts from the apex of the hyphae and proceeds towards the base. The cells give appearance of beads due to their oval or round shape. Each oidium or arthrospore develops into a new mycelium.

b) Chlamydospore: In some fungi such as Mucor and Fusarium, some intercalary or terminal segments of the hyphae accumulate large amount of food reserves and develop thick resistant walls. These thick walled spores are called chlamydospore. These cells function as perennating bodies and help in surviving unfavourable environmental conditions and are released after the intervening hyphae are degenerated. As the favourable conditions return each chlamydospore develops into a new mycelium.

Fission of unicellular thalli: This method is typical in some types of yeast such as Schizosaccharomyces. During this process, somatic cells elongate and divide transversely into

two daughter cells of similar size and shape. First the nucleus divides followed by division of the cytoplasm by wall formation dividing parent cell into two. The two daughter cells separate and can lead independent lives.

Budding of somatic cells: The yeast, Saccharomyces cerevisiae, cell reproduces by the means of budding which involves production of an outgrowth or bud from a parent cell or spore. This bud gradually enlarges, constricts and finally forms a new individual by getting separated the parent cell by formation of a cross wall. Sometimes this newly formed bud before getting separated from the parent cell produces a new bud which remains attached for a while to form a chain of buds known as **pseudomycelium**.

Rhizomorphs: In many higher fungi such as Agaricus, hyphae aggregate to form a cord like structures. These dark brown coloured fine root-like strands or hyphae are known as rhizomorphs. These serve as perennating bodies which remain dormant under unfavourable conditions and give rise to new fruiting bodies.

Sclerotia: Sclerotia, produced by Claviceps purpurea, are the modification of mycelium. They are rounded or cylindrical or irregular or cushion-shaped structures with a dense mass of thick walled hyphae. The hypha serves as the organs of perrenation and is meant for vegetative propagation. With the return of favourable conditions sclerotia germinate to form a new mycelium.

Production of asexual spores: This is the most common method of asexual reproduction in fungi wherein special reproductive cells are formed which are known as spores or mitospores. The process of formation of spores in fungi is called sporulation. These spores vary in shape i.e., globose, oval, oblong, needle-shaped to helical with a size ranges from 2-150 micron. These are septate, unicellular or multicellular (Alternaria and Curvularia), motile or non-motile, may be thin or thick-walled with hyaline or coloured pigments such as green, yellow, orange, red, brown to black. Some fungus produces only one type of spore while some can produce more than 2-3 types of spores. These spores help in perrenation, propagation and dispersal. Mitospores can be categorized into two main types depending upon their method of formation a) sporangiospore and b) conidiospore.

a) Sporangiospores: Numerous minute, uninucleate sporangiospores are produced by cleavage of the cellular content of a sac-like structure called sporangium. Each sporangium is born on hyphae called sporangiophore. Sporangiospore can be non-motile (**aplanospore**) or motile (**zoospore**).

Aplanospores: These are characteristics of terrestrial species such as Rhizopus and Mucor. Aplanospores have a definite spore wall and are dispersed by the means of wind and insects. Aplanospores develop a rigid cell wall prior to their release from sporangium.

Zoospores: In aquatic fungi (Pythium, Division-Oomycota) motile biflagellate zoospores are produced on structures called as zoosporangium. However, the motile zoospores are initially naked. They secrete a cell wall only after the swarming period is over and germinate by forming a germ tube. Zoospores may have one or more than one flagella. Basically, the fungal species have two types of flagella **1**. Tinsel type - feathery structure having a long rachis and have lateral

hair projections called mastigonemes or flimmers and **2**. Whiplash type - long basal portion and a short and flexible upper portion. Depending upon the presence and absence of these two types of flagellum zoospores are of four types:

i. Zoospore with single posterior whiplash flagellum E.g. Chytridiomycetes
ii. Zoospore with single anterior tinsel flagellum E.g. Hypochytridiomycetes
iii. Biflagellate zoospore with two anterior whiplash flagella E.g. Plasmodiophoromycetes
iv. Biflagellate zoospore with one tinsel and one whiplash flagella as in Oomycetes.

Conidiospores: These asexual spores are non-motile, deciduous and are formed externally as single separate cells either directly on the mycelium or on morphologically differentiate hyphae called conidiophores. These structures may be simple or branched and septate or aseptate. Conidia may be produced singly as in Phytophthora or in chains at the tip of conidiophores as in Aspergillus or at the tip of the branches of conidiophores as in Penicillium. Conidiophores often arise singly and are scattered in mycelium. However, sometimes they may also arise in specialized structures called fruiting bodies. Depending upon their appearance they are termed as **synnema**, **sporodochia**, **acervuli** (saucer-shaped), **pycnidia** (flask-shaped) or **pustules**.

Significance of Asexual reproduction in fungi: Asexual reproduction ensures fungi can thrive, adapt, and persist in diverse ecological niches, making them highly successful organisms in nature. Asexual reproduction in fungi is significant for several reasons:

1. **Rapid Population Growth:** Asexual reproduction allows fungi to produce large numbers of offspring quickly, ensuring the survival and spread of the species.
2. **Survival in Stable Environments:** Since asexual reproduction produces genetically identical offspring (clones), it is advantageous in stable environments where existing traits are already well-suited for survival.
3. **Efficient Spore Dispersal:** Many fungi reproduce asexually through spores (e.g., conidia or sporangiospores), which can be dispersed over long distances by wind, water, or animals.
4. **Colonization of New Habitats:** Asexual reproduction enables fungi to rapidly colonize new environments without the need for a mating partner.
5. **Resilience to Harsh Conditions:** Certain asexual structures, such as chlamydospores, help fungi survive unfavorable conditions and germinate when conditions improve.
6. **Medical and Industrial Importance:** Many fungi that reproduce asexually (e.g., Penicillium, Aspergillus) are used in medicine (antibiotics, fermentation) and industry (cheese production, enzyme production).
7. **Pathogenicity and Disease Spread:** Many fungal pathogens of plants and animals reproduce asexually, leading to rapid disease outbreaks, as seen in Candida infections or plant diseases like rusts and mildews.

Sexual Reproduction

This process involves fusion of two compatible sex cells or gametes of opposite strains. Sexual reproduction is also known as perfect state. Fungi show remarkable diversity in their process of sexual reproduction.

Sex organs in fungi: Sex organs in fungi are known as **gametangia** (sing. gametangium). Gametangia may contain differentiated sex cells called gametes or may have only one or more

nuclei as gametes. These gametangia or gametes can be morphologically similar also and they might show some morphological dissimilarity also. Morphologically similar gametangia and gametes are known as **isogametangia** and **isogametes**, respectively. However, morphologically distinct ones are known as **heterogametangia** and **heterogametes**, respectively. In the later case, female gametangium is called **oogonium** (pl. **oogonia**) in Oomycetes and **ascogonium** (pl. **ascogonia**) in Ascomycetes. The male gametangium is known as **antheridium** (pl. **antheridia**).

Most of the fungi can be distinguished into three categories on the basis of sex i) Monoecious ii) Dioecious iii) Sexually undifferentiated.

i. **Monoecious:** These are also named as hermaphroditic or bisexual. Each thallus bears both male and female sex organs which may not be compatible;
ii. **Dioecious:** Some thalli bears only male sex organs and some thalli bears only female sex organs.
iii. **Sexually undifferentiated:** In these fungi, sexual structures are produced but morphologically male and female sexual organs cannot be distinguished.

The sexual reproduction basically involves three phases viz., (I) plasmogamy (II) karyogamy (III) meiosis.

I) Plasmogamy: It is the union of protoplast of reproductive cells or hyphae to bring the nuclei of the two parents together in a pair. Although, these nuclei do not fuse with each other and the resulting cell with two nuclei is called dikaryon. This condition is unique for fungi and may continue for several generations as such. Plasmogamy occurs through a variety of mechanisms in fungi. Some of them are as follows:

1. Planogametic copulation: This process involves fusion of two gametes. Sexual reproduction in fungi can be divided into i) Isogamous, ii) Heterogamy.

i) Isogamy: Isogamy in fungal sexual reproduction refers to the fusion of gametes that are morphologically similar in size and structure, but differ in mating type, ensuring genetic compatibility E.g. Olpidium and Catenaria.
ii) Heterogamy: When the fusing gametes are morphologically as well as physiologically different. Heterogamous reproduction is of two types:

a) Anisogamy: It consists of the fusion of two motile gametes where the **male gamete is small and more active** than the female gamete, e.g., Allomyces.

b) Oogamy: In this process the **motile male gamete** antherozoid fuses with the **large, non-motile female gamete e**gg or ovum) e.g., Synchytrium etc.

2. Gametangial copulation: The two gametangia comes into contact and the entire content of the two parents fuses together and becomes one (Figure 13.1). E.g.: Rhizopus and Mucor. However, in some fungal species entire protoplast of one gamete flows into the other gamete through a pore. The recipient is female and the donor is male.

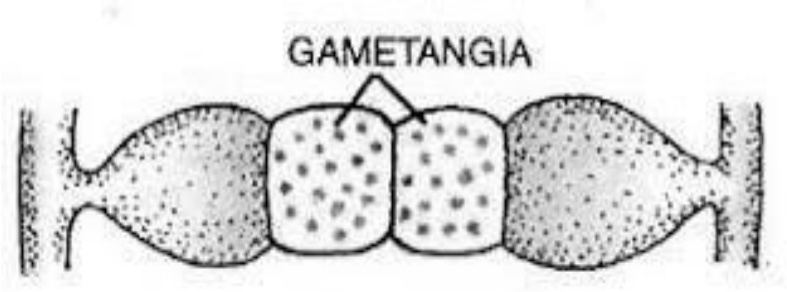

Figure-13.1: Gametangial copulation in fungi (https://tinyurl.com/55za47hx)

3. Gametangial contact: The nucleus in the antheridium represents the male gamete. Male gamete here is not a separate entity. The oogonium and the antheridium come in contact through a tube and one of the nuclei from the antheridium migrates into the oogonium (Figure 13.2). Interestingly, the two gametangia do not fuse E.g.: Penicillium, Phytophthora, Albugo, Pythium.

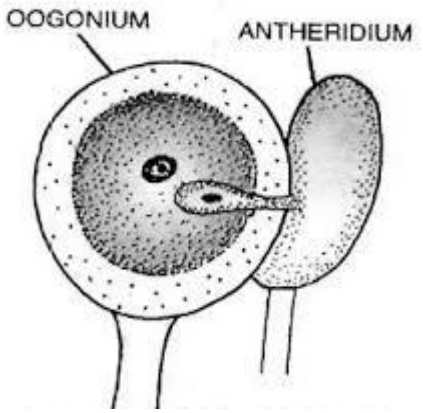

Figure-13.2: Gamentangial contact in fungi (https://tinyurl.com/5h3397ya)

4. Spermatization: This is one of the most remarkable modes of plasmogamy. The spermatia which are minute conidia like structures are produced externally on special hyphae called spermatiophore. Spermatia develop inside cavities called as spermatogonia. Female cell can be a gametangium, vegetative hyphae or even specialized receptive hyphae. E.g. Pucciniales (rust fungi)

5. Somatogamy: It involves the merging of somatic hyphae, leading to plasmogamy (cytoplasmic fusion) but not immediate nuclear fusion (karyogamy). Results in a heterokaryotic or dikaryotic stage, where nuclei from both the parents coexist in a shared cytoplasm E.g. Basidiomycota and Ascomycota.

II) Karyogamy: It is the process of fusion between two nuclei. In lower fungi, it may immediately follow plasmogamy. However, in higher fungi it may be delayed for a long time.

Types of Sexual Reproduction in Fungi based on Karyogamy

Fungi show different types of sexual reproduction based on the type of karyogamy:

a) **Zygomycota (Zygosporic Fungi):** Karyogamy occurs within a **zygosporangium**, a thick-walled structure that later undergoes meiosis. E.g. Rhizopus (bread mold).
b) **Ascomycota (Sac Fungi):** Karyogamy happens inside an **ascus**, where a diploid nucleus forms and immediately undergoes meiosis, producing ascospores. E.g. Saccharomyces, Aspergillus, Penicillium.
c) **Basidiomycota (Club Fungi):** Karyogamy takes place in a **basidium**, where it is followed by meiosis to form basidiospores. E.g. Mushrooms, Puccinia (rust fungi).
d) **Chytridiomycota (Primitive Fungi):** Karyogamy occurs within a **resting sporangium**, followed by meiosis. E.g. Batrachochytrium (chytrid fungi).

III) Meiosis: Meiosis in fungal sexual reproduction is a crucial process that generates genetic diversity. Fungi exhibit diverse reproductive strategies, but in sexually reproducing fungi, meiosis occurs after the fusion of haploid nuclei (karyogamy) to produce genetically varied spores. This process produces four genetically different spores.

Significance of sexual reproduction

Sexual reproduction in fungi is significant for several reasons:

1. **Genetic Diversity:** Sexual reproduction promotes genetic variation through recombination, allowing fungi to adapt to changing environments, resist diseases, and develop beneficial traits.
2. **Survival in harsh Conditions:** Many fungi produce hardy sexual spores (e.g., ascospores, basidiospores, zygospores) that can withstand extreme conditions like drought, heat, or lack of nutrients, ensuring survival and dispersal.
3. **Evolutionary adaptation:** The mixing of genetic material through meiosis and fusion of gametes (or gamete-like structures) leads to evolutionary advantages, helping fungi develop resistance to antifungal treatments or environmental stressors.
4. **Restoration of Genetic integrity:** Sexual reproduction can help eliminate harmful mutations by allowing recombination and selection for beneficial traits.
5. **Formation of Specialized structures:** Sexual reproduction results in complex reproductive structures like mushrooms, asci, and zygospores, which play a key role in fungal classification and life cycle progression.
6. **Ecological role:** Many fungi engage in symbiotic relationships (e.g., mycorrhizae with plants) where sexual reproduction helps to maintain a stable and diverse population that benefits ecosystems.

13.3 PARASEXUALITY

Fungi exhibit diverse reproductive strategies, including sexual and asexual reproduction. Unlike conventional sexual reproduction, which involves coordinated meiosis and mating cycles, parasexuality allows fungi to achieve genetic diversity through a somatic process that bypasses strict sexual phases. They recombine their genes by some novel non-sexual process. This process

enables genetic recombination without meiosis, providing an alternative means for genetic variation and adaptability. This mechanism is particularly vital for "imperfect fungi" (Deuteromycetes), which lack observable sexual stages, and has been increasingly recognized as a driver of evolution in pathogenic and industrial species. Recent advances in genomics and molecular biology have shed light on the ecological and evolutionary significance of parasexuality, revealing its role in antifungal resistance, horizontal gene transfer (HGT), and adaptive innovation. Guido Pontecorvo and Roper (1956) first reported it in the mold, Aspergillus nidulans. Under this phenomenon, the process of **plasmogamy, karogamy and haplodization** take place, but not at specified time or specified points in the life cycle of the fungus.

Mechanisms of Parasexuality

Parasexuality in fungi involves a sequence of cytological events that lead to genetic recombination. The process includes the following stages:

1. **Heterokaryosis**: The initial step involves the fusion of hyphae from genetically distinct individuals, leading to a heterokaryotic state in which different nuclei coexist within the same cytoplasm. This occurs through anastomosis, a process where fungal hyphae merge, allowing the exchange of cytoplasmic and nuclear material.
2. **Nuclear Fusion (Karyogamy)**: In a subset of cells, the distinct nuclei within the heterokaryotic mycelium undergo karyogamy, forming diploid nuclei. This step is similar to the fusion of gametes in sexual reproduction but occurs randomly and without the formation of specialized reproductive structures.
3. **Mitotic Recombination**: The diploid nuclei may undergo mitotic recombination, which allows genetic exchange between homologous chromosomes. Unlike meiotic recombination, which occurs during sexual reproduction, mitotic recombination occurs during cell division, resulting in genetic diversity without undergoing meiosis.
4. **Haploidization**: Over time, some diploid nuclei may revert to a haploid state through chromosome loss during mitotic divisions. This process generates new genetic combinations, leading to the emergence of novel phenotypic traits in the fungal population.

Significance of Parasexuality in Fungi

Parasexuality offers several evolutionary advantages for fungi, particularly those lacking a traditional sexual cycle. Some of its key contributions include:

Evolutionary and Ecological Significance

Parasexuality provides an evolutionary shortcut, allowing fungi to adapt rapidly to hostile environments. For pathogens, this translates to accelerated host adaptation and drug resistance. For instance, in Candida albicans, a human commensal turned pathogen, parasexual

recombination facilitates the spread of mutations conferring resistance to azoles and echinocandins. Recent studies suggest that parasexuality in Candida auris a multidrug-resistant "superbug" enables the transfer of resistance genes between clades, complicating clinical management. Moreover, parasexuality blurs the line between asexual and sexual fungi. Genomic analyses reveal that even species with known sexual cycles, like Aspergillus fumigatus, engage in parasexuality under stress, creating hybrid genotypes with enhanced virulence. Parasexual recombinants of Fusarium oxysporum exhibit novel toxin profiles, enabling jumps to new plant hosts.

Modern Insights: Molecular Mechanisms and Horizontal Gene Transfer

Advances in CRISPR-Cas9 editing and live-cell imaging have clarified the molecular underpinnings of parasexuality. Key genes regulating hyphal fusion (e.g., ham genes in Neurospora crassa) and nuclear behavior (e.g., nud genes controlling cytoplasmic dynein in A. nidulans) are conserved across fungi. Notably, the het (heterokaryon incompatibility) genes, which limit fusion to genetically compatible strains, act as a checkpoint to prevent parasitic nuclei from exploiting heterokaryons.

Parasexuality also facilitates HGT, a process once deemed rare in eukaryotes. By using long-read sequencing researchers documented HGT of entire metabolic gene clusters between Aspergillus species via parasexual hybrids. Such transfers enable fungi to rapidly acquire traits like toxin production or xenobiotic degradation, with implications for bioremediation and antibiotic discovery.

Applications in Biotechnology and Medicine

The parasexual cycle has significant implications for biotechnology, agriculture, and medicine. Researchers have harnessed parasexual mechanisms to create industrially valuable fungal strains with desirable characteristics, such as improved enzyme production or enhanced resistance to environmental stressors. For example, parasexual hybridization of Trichoderma reesei strains has yielded hyper cellulolytic variants used in biofuel production. Similarly, Penicillium chrysogenum hybrids generated through parasexuality show enhanced penicillin titers. In medicine, understanding parasexuality in pathogenic fungi is crucial for developing strategies to combat fungal infections, especially those caused by drug-resistant strains. Cryptococcus neoformans employs parasexuality to diversify its genome within macrophages, evading host immune responses. Targeting proteins involved in hyphal fusion or nuclear segregation could disrupt this process, offering new therapeutic avenues. Additionally, parasexuality has applications in genetic engineering, as scientists can manipulate fungal genomes through controlled nuclear fusion and recombination. This technique is useful for strain improvement in fungi used in fermentation, bioremediation, and pharmaceutical production.

Hybrid Formation: In some fungi, parasexuality enables the fusion of different species or strains, leading to the creation of hybrid organisms with novel genetic traits. Such hybrids may exhibit enhanced fitness, virulence, or environmental adaptability.

13.4 SUMMARY

Asexual reproduction in fungi is a prevalent and efficient process that allows rapid propagation without genetic recombination, yielding genetically identical offspring (clones). This method is advantageous in stable environments, enabling quick colonization and resource exploitation. Key mechanisms include: 1. Spore Production: Conidia: Externally borne on specialized hyphae called conidiophores; seen in Penicillium and Aspergillus (Ascomycetes). Sporangiospores**:** Formed internally within sac-like sporangia on sporangiophores; characteristic of zygomycetes like Rhizopus. Other spores include chlamydospores (thick-walled, stress-resistant) and arthrospores (from hyphal fragmentation). Budding: Common in yeasts (e.g., Saccharomyces cerevisiae), where a daughter cell pinches off from the parent. Fragmentation: Hyphae break into pieces, each growing into a new organism (e.g., molds). Asexual reproduction ensures rapid spread and energy efficiency, bypassing the need for a mate. However, it limits genetic diversity, potentially reducing adaptability to environmental changes. Many fungi employ both asexual (anamorphic) and sexual (teleomorphic) phases, balancing clonal spread with genetic variation when necessary. This adaptability underscores fungi's ecological success and versatility.

Sexual reproduction in fungi enhances genetic diversity and adaptation, typically occurring under environmental stress or nutrient scarcity. The process involves several key stages: 1. Plasmogamy: Fusion of cytoplasm from two compatible mating types (e.g., + and – strains), mediated by pheromones. This results in a dikaryotic cell (n + n), where two haploid nuclei coexist without immediate fusion. 2. Dikaryotic Stage: The dikaryon forms a mycelium with paired nuclei, which may persist extensively, as in Basidiomycetes. This stage is critical for growth and development in some species. 3. Karyogamy: Nuclear fusion within specialized structures (e.g., ascus, basidium) produces a transient diploid zygote (2n). 4. Meiosis: The diploid nucleus undergoes meiosis, generating haploid spores (e.g., ascospores, basidiospores, zygospores) housed in structures characteristic of each fungal phylum: Ascomycota: Spores develop in sac-like asci. Basidiomycota: Spores form on club-shaped basidia. Zygomycota: Thick-walled zygospores arise from gametangia fusion. Spore Dispersal: Haploid spores disperse, germinating into new haploid mycelia, completing the cycle. Sexual reproduction promotes genetic variation, aiding fungal adaptation to changing environments. While some fungi rarely exhibit sexual phases (classified as Deuteromycetes), others rely on it for survival. This process underscores the ecological resilience and evolutionary success of fungi across diverse habitats.

Parasexuality in fungi is a unique mechanism that facilitates genetic recombination without the need for meiosis. This process enhances genetic diversity, adaptability, and evolutionary

potential in fungal populations, particularly in species that lack a traditional sexual cycle. Understanding the parasexual cycle has broad implications for fungal biology, agriculture, and medicine, influencing the development of antifungal strategies and the improvement of industrially relevant fungal strains. As research continues to uncover the molecular mechanisms underlying parasexuality, its role in fungal genetics and evolution will become increasingly significant.

13.5 TECHNICAL TERMS

Budding, Cell Wall, Chitin, Coenocytic, Conidiophore, Conidia, Conjugation, Imperfect Fungi, Fission, Gametangium, Haustoria, Host, Mycorrhiza.

13.6 SELF ASSESSMENT QUESTIONS

Q.1 Describe the types of sexual reproduction in fungi.
Q.2 Explain the various types of asexual reproduction in fungi.
Q.3 Give an account on the significance of sexual and asexual reproduction in fungi.

13.7 SUGGESTED READINGS

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Prof. A. Amruthavalli

LESSON – 14

AINSWORTH CLASSIFICATION OF FUNGI

OBJECTIVE OF THE LESSON

Students are able to know the latest updates and Ainsworth classification of fungi and their systematic position based on various factors.

STRUCTURE OF THE LESSON

14.1 INTRODUCTION

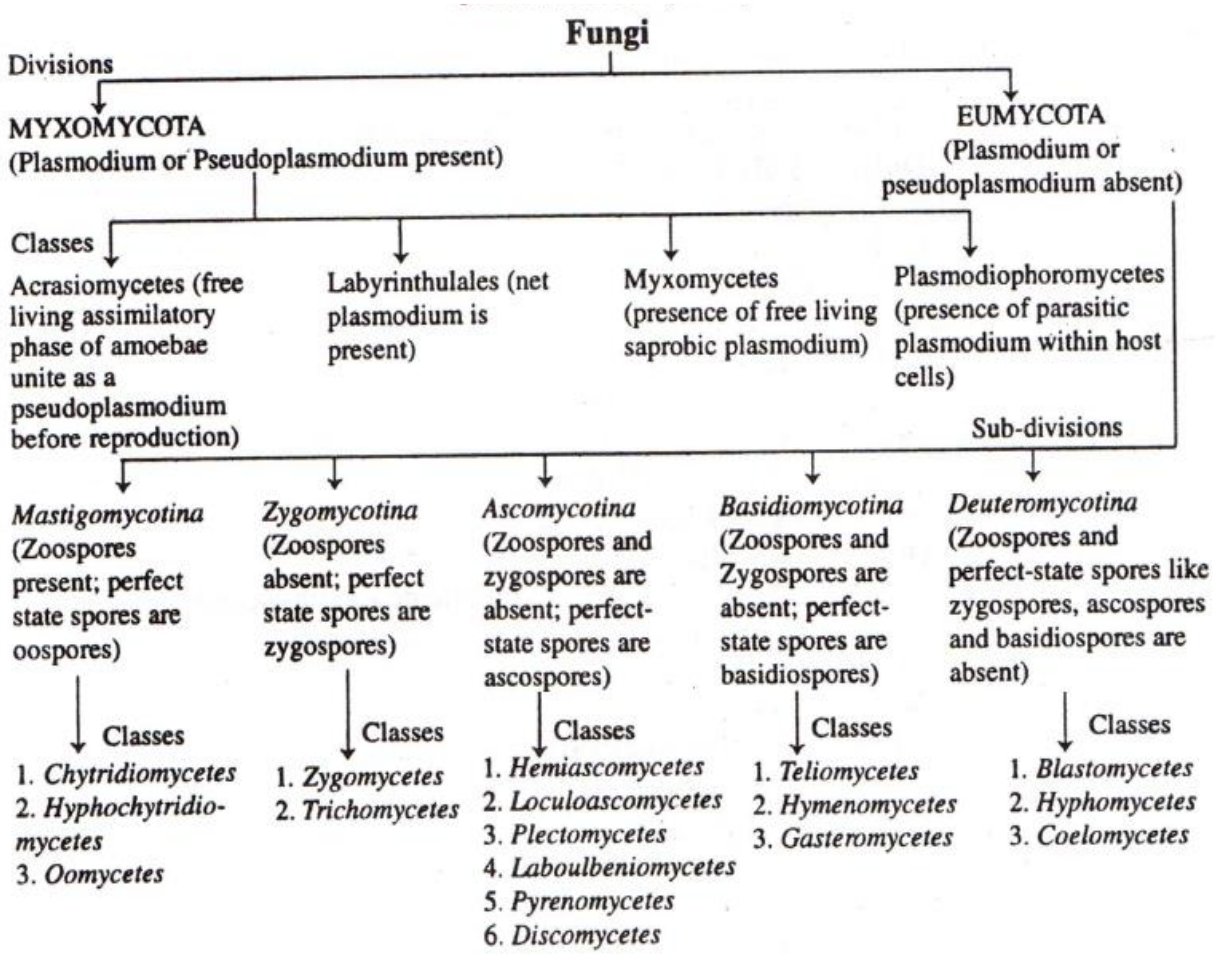
The word "**classification**" may be defined as "**the scientific categorization of organisms in a hierarchical series of group".** In spite of the existence of many varieties, biological strains and physiological or cultural races, the **species is** generally considered as the smallest group**.** More similar species are grouped together into genus, similar genera are grouped into family, families into order, orders into class, similar classes into division, division into kingdom, and kingdom into domain or super kingdom. Fungi classified on the basis of seven characteristic features like i. Morphological characters ii. Host specialization iii. Physiological characters iv. Cytological and genetical characters v. Serological characters vi. Biochemical characters vii. Numerical taxonomy

Recommendations of International Committee: The committee on International Rules of Botanical Nomenclature recommended the use of following "suffixes" for the division and other major categories of fungi: Division should end in mycota. Sub-division should end in mycotina. Classes should end in mycetes. Sub-classes should end in mycetidae. Order should end in ales. Family should end in aceae. No standard ending have been proposed for genera and species. Species are sometimes broken into varieties, forms and physiological races i.e. Eukaryotic (with true nuclei), Achlorophyllous (without chlorophyll), unicellular, or multicellular organisms, microscopic or macroscopic in size. Usually all cells are with cell walls and filaments. Fungi typically reproducing by spores produced asexually or sexually. Cell walls contain chitin, cellulose, or both. Fungi contain about 50,000 living species. Around 500 fossil species are known until now.

The **Ainsworth Classification of Fungi** (1973) is a system for classifying fungi that was developed by **Geoffrey Clough Ainsworth**, a British mycologist. His classification was widely recognized and used for fungal taxonomy, particularly in earlier fungal systematics. Ainsworth classified fungi into major groups based on morphological, reproductive, and physiological characteristics. The classification primarily followed a **hierarchical system**, organizing fungi into different **divisions, classes, orders, families, genera, and species**.

14.2 DIVISION MYXOMYCOTA

Myxomycota, commonly known as “plasmodial slime molds” or "true slime molds," belong to the class Myxogastria within the phylum Amoebozoa. Historically classified under fungi due to their spore-producing fruiting bodies, modern molecular phylogenetics has reclassified them within the super group Amoebozoa, highlighting their closer relation to amoebae than fungi. This reclassification arose from differences in life cycle, motility, and nutritional strategies. Myxomycota thrive in humid, temperate forests, inhabiting decaying logs, leaf litter, and soil. They favor microhabitats with abundant microbial prey and are globally distributed, from tropical rainforests to Arctic tundras. Some species exhibit niche specificity, while others are cosmopolitan. The vegetative phase is a plasmodium, it is a multinucleate, acellular mass enveloped by a membrane. This coenocytic structure exhibits shuttle streaming (rhythmic cytoplasmic flow) for movement and nutrient distribution.



Unlike cellular slime molds (e.g., *Dictyostelium*), Myxomycota form a single, large plasmodium without individual cell walls, allowing phagocytosis of bacteria, fungi, and organic debris. The definite cell wall is absent from their amoeba like bodies. Plasmodia navigate via chemotaxis, moving toward food sources or away from hazards, capable of covering several centimeters per hour. Spores are provided with firm walls. Flagellated cell are characteristically produced. Wall-less organisms possess either a Plasmodium (a mass of naked multinucleate protoplasm having amoeboid movement) or a pseudoplasmodium (an aggregation of separate amoeboid cells). Both are of slimy consistency, hence slime molds. The life cycle alternates between asexual and sexual phases which include I) Haploid and diploid phases: 1. Asexual reproduction: Spores germinate into haploid myxamoebae or flagellated swarm cells. 2. Sexual reproduction: Fusion of haploid cells forms a diploid zygote, developing into the plasmodium. II) Fruiting bodies: Under stress, the plasmodium forms sporangia or intricate fruiting bodies (e.g., *Physarum*), releasing resistant spores.

The division myxomycota again divided into four classes i.e. 1. Class. Acrasiomycetes (cellular slime molds) 2. Class. Hydromyxomycetes (net slime molds) 3. Class. Myxomycetes (true slime molds) 4. Class. Plasmodiophoromycetes (endo-parasitic slime molds).

Class 1: Acrasiomycetes: Acrasiomycetes is a class of fungi-like protists that belong to the phylum Amoebozoa**.** These organisms are commonly referred to as cellular slime molds and are distinguished by their unique life cycle, which involves both unicellular and multicellular stages**.** They are important for studying cellular communication, differentiation, and aggregation. The vegetative stage consists of individual amoeba-like cells that move and feed independently. Under unfavorable conditions individual amoebae aggregate to form a multicellular structure called a pseudoplasmodium or a slug. Unlike fungi, the vegetative cells lack a rigid cell wall, making them flexible and motile. Generally found in soil, decaying organic matter, and moist environments. The life cycle of Acrasiomycetes alternates between unicellular and multicellular stages, primarily in response to environmental conditions. The life cycle of Acrasiomycetes includes A) Vegetative Phase - individual cells exist as haploid amoeboid forms. These amoebae move using pseudopodia and feed on bacteria and organic debris via phagocytosis. B) Aggregation Stage - when food becomes scarce, amoebae release signaling molecules (e.g., cyclic AMP). The amoebae chemotactically move towards the signal and aggregate into a slug-like structure (pseudoplasmodium). The slug moves as a coordinated unit toward light and heat. C) Fruiting Body Formation - the slug stops moving and undergoes differentiation. Some cells form a stalk, while others develop into spores. The spores are enclosed in a protective coat and remain dormant until favorable conditions return. D) Spore Germination - when environmental conditions improve, the spores germinate and release new amoeboid cells, restarting the life cycle. Acrasiomycetes fungi help in the break- down organic material in soil which serves as food for soil-dwelling microorganisms. Used in studies of cell communication and differentiation. May help in understanding cell signaling relevant to cancer research. Potential applications in bioremediation. E.g. 1. *Dictyostelium* - most studied cellular slime mold and used as a model organism in genetics and cell biology. 2. *Polysphondylium* - similar to *Dictyostelium* but forms symmetrical fruiting bodies. 3. Acrasis - shows unique aggregation behavior.

Class 2: Labyrinthulales: Labyrinthulales are mostly found in marine and estuarine environments, thriving on decaying organic material, algae, and plant debris. Some species can

also be found in freshwater or soil habitats. Unlike Myxomycota, which form a plasmodium, Labyrinthulales produce an extracellular network of mucilaginous slime tracks. Cells glide along these tracks to facilitate movement and nutrient absorption. They absorb nutrients directly from their environment, a process called osmotrophy. Many are saprotrophs, decomposing organic material, while some are parasites of marine plants, algae, and even mollusks. Unlike true slime molds, Labyrinthulales do not form a multinucleate plasmodium. Cells are generally uninucleate and move individually along the slime tracks. Cells are enclosed in a thin wall and can transform into sporangia under suitable conditions. Asexual reproduction occurs via binary fission or zoospore formation. Some species may exhibit sexual reproduction, but it is not well understood. Some members, such as *Labyrinthula*, cause diseases in marine plants. For example, *Labyrinthula zosterae* is responsible for wasting disease in eelgrass (*Zostera marina*). *Labyrinthulales* are part of the heterokont group, closely related to oomycetes (water molds) and diatoms. They possess biflagellate zoospores in some life stages, a characteristic feature of stramenopiles. The key genera of Labyrinthulales includes *Labyrinthula* (parasitic and saprotrophic species, associated with eelgrass wasting disease); *Thraustochytrium* (important for their production of omega-3 fatty acids and industrial applications); *Aurantiochytrium* (found in marine environments, involved in decomposing organic material).

Class 3: Myxomycetes: These are unique in the sense that they exhibit characteristics of both fungi and protozoa. There are approximately 1,000 species of Myxomycetes known until now. These species vary widely in terms of the morphology of their fruiting bodies and the types of plasmodial forms they exhibit. The fruiting bodies can vary in shape, size, and color, ranging from simple sporangia to more complex structures with stalks or umbrellas. The color of the sporangium can be yellow, orange, red, purple, or black, depending on the species. They are often found in temperate forests but can also inhabit other moist habitats around the world. Myxomycetes are commonly found in moist, decaying environments such as forest floors, decaying logs, and leaf litter. They play an important role in nutrient recycling as decomposers, breaking down complex organic material into simpler compounds. Myxomycetes are primarily saprophytic and feed on decaying organic matter. They are also capable of phagocytosis, engulfing bacteria and small organic particles. The plasmodium moves across substrates in search of food, and its ability to digest organic material is a key aspect of its ecological role as decomposers in forest ecosystems. Myxomycetes are often grouped with slime molds that form a complex lifecycle with two distinct phases: one is the plasmodial phase - a multinucleate, non-septate mass of cytoplasm, and the other is the spore-forming stage. The most distinctive feature of Myxomycetes is the formation of a plasmodium. This is a large, amorphous, multinucleate mass of cytoplasm that moves and feeds in a manner similar to an amoeba. The plasmodium does not have cell walls, but it is capable of engulfing and digesting food particles, especially bacteria, fungi, and decaying organic matter. The plasmodium exhibits cytoplasmic streaming, where the cytoplasm flows in an organized way, allowing the plasmodium to move and explore the environment. This movement can be quite rapid. The plasmodium, under favorable conditions, will differentiate and produce fruiting bodies. These fruiting bodies are often spore-bearing and may be in the form of sporangia or similar structures. These fruiting bodies are typically composed of stalked or sessile structures containing spores. Myxomycetes reproduce sexually and asexually. **Asexual reproduction** is achieved through the release of spores from the fruiting bodies, which can disperse and germinate into new myxamoebae. **Sexual reproduction** occurs when two myxamoebae fuse to form a diploid zygote, which then develops into the

plasmodium. The plasmodium eventually produces fruiting bodies that release sexual spores. The life cycle of Myxomycetes is highly complex and involves the following stages:

a) **Germination of spores**: The cycle begins when a spore germinates, producing a motile cell called a myxamoeba (a flagellate or amoeboid cell).
b) **Myxamoebae stage**: These cells can feed on bacteria and move via pseudopodia (in amoeboid form) or flagella. In some species, two myxamoebae may fuse to form a zygote, which initiates the next phase of the life cycle.
c) **Plasmodium formation**: When conditions are favorable, the myxamoebae can fuse and merge to form the plasmodium. This is the vegetative or feeding stage of the organism.
d) **Fruiting body formation**: Upon reaching maturity, the plasmodium undergoes a transformation to produce a fruiting body. This fruiting body releases new spores that will begin the cycle anew.
e) **Spore production**: Inside the fruiting body, the spores are produced and are typically released into the environment to germinate into new amoebae or flagellates, completing the cycle.

Myxomycetes are a subject of interest for research in a variety of fields, including **c**ell biology, microbiology, and ecology. The plasmodial stage, with its large, multinucleate structure, provides insights into the regulation of nuclear division and the control of cytoplasmic streaming. Their ability to form large, dynamic plasmodial masses and their complex life cycle offer a unique opportunity to study the cellular differentiation, communication, and development. E.g. 1. *Physarum* - a genus that contains species like *Physarum polycephalum*, which is often used in laboratory studies. Its plasmodium can move and solve mazes, making it a subject of interest in research on decision-making and pattern formation. 2. *Fuligo* - known for producing a bright yellow, spongy fruiting body. 3. *Comatricha* - a species that has distinctive sporangia with stalks. 4. *Amaurochaete* - another genus with intricate and distinctive fruiting body structures.

Class 4: Plasmodiophoromycetes: Class Plasmodiophoromycetes belongs to the division Myxomycota within the kingdom Fungi. Plasmodiophoromycetes are known for their significant role in plant pathology, causing various diseases such as clubroot of crucifers (*Plasmodiophora brassicae*) and powdery scab of potatoes (*Spongospora subterranea*). These are intracellular parasites of vascular plants and algae, infecting root tissues. The main vegetative body is a multinucleate plasmodium, similar to slime molds, but confined within host cells. They reproduce by biflagellate zoospores, which serve as the primary means of infection. Unlike true fungi, they lack a filamentous mycelial network. The life cycle is biphasic, consisting of two main stages: 1. Primary Infection (Zoospore Stage) - The resting spores germinate under favorable conditions, releasing primary biflagellate zoospores. Zoospores swim in water films and infect host root hairs. Inside the root cells, the zoospore develops into a primary plasmodium that undergoes nuclear division. 2. Secondary Infection (Resting Spore Formation) - The primary plasmodium cleaves into secondary zoospores, which reinfect other root cells. The secondary infection cycle eventually results in the formation of resting spores, which are released back into the soil as the host tissue decays. These spores can remain dormant in the soil for years, ensuring long-term survival. Plasmodiophoromycetes are responsible for severe plant diseases, leading to crop losses. Resting spores persist in the soil, making disease management difficult. Some species facilitate the transmission of plant viruses. Due to their soil borne nature and long-lived

spores, they are difficult to eradicate. E.g. 1. *Plasmodiophora brassicae* - causal agent of Clubroot disease. Infects members of the Brassicaceae family (e.g., cabbage, broccoli, mustard). Causes swelling and deformation of roots, leading to poor nutrient uptake and stunted growth. Disease spreads through contaminated soil and water. 2. *Spongospora subterranea* - Causal Agent of Powdery Scab in Potatoes. Affects potato roots and tubers, leading to scab-like lesions. Also acts as a vector for Potato Mop-Top Virus (PMTV). Survives in soil through persistent resting spores. 3. *Polymyxa betae* - Vector of Beet Necrotic Yellow Vein Virus. Infects sugar beet roots and acts as a vector for Beet Necrotic Yellow Vein Virus (BNYVV), which causes rhizomania disease. Unlike *Plasmodiophora brassicae*, it does not cause visible galls but severely affects root function.

14.3 DIVISION EUMYCOTA

Eumycota, or "true fungi," is a division of the kingdom Fungi that includes organisms with well-defined characteristics. These fungi play important ecological roles as decomposers, symbionts, and pathogens. They have well-organized nuclei within membrane-bound organelles. They lack flagella or cilia, except in some primitive groups. They absorb nutrients from organic matter through extracellular digestion. Can be saprophytic (decomposers), parasitic, or mutualistic (e.g., mycorrhizal fungi). Their cell walls contain chitin, a strong, nitrogenous polysaccharide (unlike plants, which have cellulose). Exist as unicellular (yeasts) or multicellular (molds, mushrooms, etc.). The multicellular form consists of hyphae, which together form a mycelium. Unlike plants, fungi cannot photosynthesize and must obtain organic material for energy. Store carbohydrates as glycogen, similar to animals (unlike plants, which store starch). These break down dead organic matter, recycling nutrients. Form mutualistic relationships (e.g., lichens, mycorrhizae). Cause diseases in plants, animals, and humans (e.g., rusts, athlete's foot). Can reproduce sexually or asexually through spores. Asexual reproduction often involves spores like conidia or sporangiospores. Sexual reproduction includes zygospores, ascospores, or basidiospores, depending on the fungal group. Division Eumycota is divided into five sub-divisions, basing on the formation of sexual spores or asexual spores, **1. Mastigomycotina 2. Zygomycotina 3. Ascomycotina 4. Basidiomycotina 5. Deuteromycotina**

Sub-division Mastigomycotina: Fungi with centrioles present in this sub division. Flagellate cells typically produced during the life cycle. Nutrition is typically absorptive. Varying from unicellular that becomes converted into a sporangium, to an extensive, filamentous, coenocytic mycelium. Perfect spores are typically oospores and asexual reproduction occurs typically by zoospores. Sexual reproduction occurs by various means. Sub-division Mastigomycotina divides into 3 classess **1**. Chitridiomycetes **2**. Hypochytridiomycetes **3**. Oomycetes.

Class 1 Chytridiomycetes: These are posteriorly uniflagellated, unicellular or filamentous fungi. These fungi may be holocarpic (having all of the thallus involved in the formation of the fruiting body) or Eucarpic. Motile cells (zoospores or planogametes) are produced characterized by a single, posterior, whiplash flagellum. Mostly aquatic fungi and saprobic or parasitic on algae, fungi, or, less often, on flowering plants.

Class 2 Hyphochytridiomycetes: These are aquatic fungi. Motile cell possess a single anterior tinsel flagellum (i.e., a flagellum with short side branches along the central axis, comb-like). Parasitic on algae and fungi or saprobic on plant and insect debris in the water. It includes a single order Hypochytriales.

Class 3 Oomycetes: Fungi with well developed coenocytic mycelium. Aquatic, amphibious, or terrestrial fungi, saprobic, facultatively (occasionally) or obligately (invariably) parasitic on plants, a few on fish. Reproduce Asexually by means of flagellate zoospores each bearing one tensilflagellum directed forward and one whiplash flagellum directed backwards. Zoospores formed in sporangia of various types. Perfect spores are oospores. Sexual reproduction usually by contact of differentiated gametangia (gamete-or sex-cell-producing structures) with nuclei from the male fertilizing differentiated eggs and resulting in thick-walled oospores. Thallus probably diploid with meiosis occurring in the gametangia. This class includes 4 orders **1**. Saprolegniales **2**. Leptomitales **3**. Lagnidales **4**. Peronosporales

Sub-division Zygomycotina: Zygomycotina, commonly known as zygote fungi or conjugation fungi, is a sub-division of the fungal division Eumycota. Mostly terrestrial; found in soil, decaying organic matter, and food. Many species are saprophytic, decomposing organic material, while others are parasitic or mutualistic. Saprophytic (e.g., *Rhizopus*), Parasitic (e.g., *Entomophthora* on insects), Mutualistic (e.g., mycorrhizal association by *Glomus*). Filamentous fungi with coenocytic (aseptate) hyphae. Septa appear only in older hyphae or at reproductive structures. These fungi are primarily terrestrial and are characterized by the formation of thick-walled zygospores during sexual reproduction. Asexual reproduction occurs by sporangiospores, which are produced within sporangia borne on sporangiophores. Sexual reproduction takes place via zygosporangia and zygospores formed by the fusion of gametangia from two compatible hyphae. These fungi spoilage food (e.g., *Rhizopus stolonifer* causing bread mold). These fungi have various industrial applications (e.g., enzyme and organic acid production). Acts as biocontrol agents against insect pests. Pathogenic species causing infections like mucormycosis in humans. The zygomycotina is further classified into two major classes: 1. Zygomycetes 2. Trichomycetes.

1. Class Zygomycetes: Largest class within Zygomycotina. Mostly saprophytic, decomposing organic matter. Some are opportunistic pathogens. This class divided into three orders i) Order: Mucorales (Common molds) - fast-growing, saprophytic fungi. Produce sporangiospores in large sporangia. Can cause opportunistic infections (zygomycosis/mucormycosis). E.g. *Rhizopus stolonifer* – black bread mold; *Mucor mucedo* – found in soil and decaying vegetation; *Absidia* – involved in food spoilage and sometimes infections. ii) Order: Entomophthorales - Insect and animal pathogens. Used in biological control of pest insects. E.g. *Entomophthora muscae* – infects and kills houseflies; *Basidiobolus ranarum* – causes sub-cutaneous infections in animals and humans. iii) Zoopagales - mostly parasitic or predatory on microscopic eukaryotes. Found in soil, decaying organic matter, or aquatic environments. Non-motile and reproduce by spores. Their hyphae are often coenocytic. E.g. *Zoopage* sp. – predatory fungus that traps small nematodes and amoebas; *Piptocephalis* sp. – a mycoparasitic fungus that infects other fungi. *Syncephalis* sp. – another mycoparasite that attacks Mucorales fungi. *Rhopalomyces* sp. – parasitic fungus that infects small arthropods.

2. Class Trichomycetes: Mostly symbiotic fungi found in the guts of arthropods. Live as commensals or mutualists in aquatic insect larvae. Do not form zygospores but have characteristics similar to Zygomycetes. This class divided into four main orders 1. **Order: Harpellales -** found in the guts of aquatic insects. Form branched filaments with specialized attachment structures. E.g. *Harpella sp.* – found in the gut of aquatic insect larvae. 2. **Order: Asellariales -** found in terrestrial isopods. Form intracellular symbiosis. E.g. *Asellaria sp.* – lives

inside crustaceans. iii) Amoebidiales - Amoebidiales are typically ectocommensals or parasites of aquatic arthropods, such as insect larvae and crustaceans. iv) Eccrinales - Eccrinales are commensal organisms found in the digestive tracts of arthropods, including crustaceans (e.g., crabs, shrimp) and insects (e.g., millipedes and cockroaches).

Sub-division Ascomycotina: The sub-division Ascomycotina belongs to the division Eumycota, which consists of true fungi. These fungi are characterized by the presence of ascus (plural: asci), a sac-like structure that produces ascospores, typically in groups of eight. Ascomycotina is one of the largest groups of fungi, including both microscopic yeasts and large, complex fungi like morels and truffles. These fungi are saprobic or parasitic on plants, animals, or humans. Some are unicellular but most are filamentous, the hyphae septate with one rarely more, perforations in the septa. Cells are uninucleate or multinucleate. Asexual reproduction takes place by fission, budding, fragmentation, or, more typically, by conidia usually produced on special sporiferous (spore-producing) hyphae, the conidiophores, which are borne loosely on somatic (main-body) hyphae or variously assembled in asexual fruiting bodies. Sexual reproduction occurs by various means resulting in the production of meiospores (ascospores) formed by free-cell formation in saclike structures (asci), which are produced naked or, more typically, are assembled in characteristic open or closed fruiting bodies (ascocarps). Among these fungi the largest and most commonly known ascomycetes are the morels, cup fungi, saddle fungi, and truffles. This subdivision divided into six classes.

Class 1: Hemiascomycetes (Primitive Ascomycetes): Simple structure, mostly unicellular or with very simple mycelium. Fungi lack ascocarps (fruiting bodies). Asexual reproduction takes place by budding or fission. Sexual reproduction occurs through the formation of asci without a fruiting body. It has a single order Saccharomycetales (Yeasts). E.g. *Saccharomyces cerevisiae* (Baker's yeast), *Candida albicans* (Pathogenic yeast), *Schizosaccharomyces pombe* (Fission yeast).

Class 2: Plectomycetes (Cleistothecial Ascomycetes): Produces a cleistothecium (closed fruiting body) where asci are enclosed. Found in soil, decaying organic matter, or as plant pathogens. Asexual reproduction occurs via conidia. This class divides into two main orders i) **Order: Eurotiales** - common mold fungi. E.g. *Aspergillus niger* (Black mold, industrial enzyme producer), *Penicillium chrysogenum* (Source of penicillin), *Eurotium herbariorum* (Food spoilage fungus). ii) **Order: Onygenales -** keratin-decomposing fungi. E.g. *Trichophyton rubrum* (Causes athlete's foot), *Histoplasma capsulatum* (Causes histoplasmosis).

Class 3: Pyrenomycetes (Perithecial Ascomycetes): Produces a perithecium, a flask-shaped fruiting body. Asci are produced inside the perithecium with a small opening for spore release. Many are plant pathogens or decomposers. This class includes mainly three orders. i) **Order: Hypocreales** - soft-textured fungi, often brightly colored. E.g. *Fusarium oxysporum* (Causes wilt diseases in plants), *Trichoderma harzianum* (Used for biological control). ii) **Order: Sordariales -** soil-inhabiting fungi, decomposers. E.g. *Neurospora crassa* (Model organism in genetics). iii) **Order: Xylariales** - wood-decaying fungi. E.g. *Xylaria polymorpha* (Dead man's fingers, a decomposer).

Class 4: Discomycetes (Apothecial Ascomycetes): Produce apothecia, an open, cup-shaped fruiting body. Asci are exposed for efficient spore dispersal. Includes edible fungi and plant

pathogens. This class includes two main orders i) **Order: Pezizales** - cup fungi. E.g. *Morchella esculenta* (Morel mushroom, edible), *Tuber melanosporum* (Black truffle, gourmet delicacy). ii) **Order: Helotiales** - leaf-inhabiting fungi. E.g. *Sclerotinia sclerotiorum* (Causes white mold disease in plants).

Class 5: Loculoascomycetes (Bitunicate Ascomycetes): Produce bitunicate asci, meaning the ascus has two layers. Usually found in decaying wood or as pathogens of plants. Fruiting bodies are often dark-colored, called pseudothecia. This class divies into two main orders. i) **Order**: **Dothideales** - pathogens of plants, forming black fungal spots. E.g. *Venturia inaequalis* (Causes apple scab disease). ii) **Order: Pleosporales** - mostly saprophytic or parasitic fungi. E.g. *Alternaria alternata* (Common plant pathogen, causes leaf spots).

Class 6: Laboulbeniomycetes: This class of fungi includes microscopic, obligate ectoparasites primarily found on arthropods, such as insects and millipedes. These fungi are unique because they do not form traditional mycelia; instead, they develop as small, multicellular thalli that attach to the external cuticle of their hosts. They rely entirely on their hosts for survival but do not usually cause severe harm. They have haustoria-like structures that penetrate the host cuticle for nutrient absorption. They produce ascospores, which are directly transferred between hosts through physical contact. Many species are adapted to specific insect hosts. Laboulbeniomycetes is divided into two main orders. i) **Order: Laboulbeniales** - The largest and most well-known order in Laboulbeniomycetes. This order consists of microscopic, obligate ectoparasites that attach to the exoskeletons of arthropods (mainly insects and millipedes). These fungi form small, complex thalli instead of typical fungal mycelia. These are reproduces via ascospores that spread through direct contact between hosts. E.g. *Laboulbenia*, *Hesperomyces*, *Rickia*. ii) **Order:** Pyxidiophorales - a less-studied order that includes fungi associated with arthropods but with a different ecological role. Some species are thought to be involved in fungal spore dispersal via insects. Unlike Laboulbeniales, they can form mycelia and have a different method of spore transmission. E.g. *Pyxidiophora*.

Sub-division Basidiomycotina: This subdivision includes a vast group of fungi commonly known as club fungi, which produce their sexual spores on a specialized cell called a basidium. Mycelium is usually septate and dikaryotic (each cell contains two nuclei from different parental strains). The hyphae have dolipore septa, which help regulate cytoplasmic flow. Asexual reproduction is usually absent but may occur through conidia, oidia, or chlamydospores. Sexual reproduction involves plasmogamy (fusion of protoplasts), karyogamy (fusion of nuclei), and meiosis, leading to the formation of basidiospores on a structure called the basidium. The dikaryotic phase is dominant in their life cycle. A basidium is a club-shaped structure that bears four haploid basidiospores externally on sterigmata. The spores are forcibly discharged in many species. Many basidiomycetes are saprophytic, decomposing wood, leaf litter, and organic matter. Some are parasitic, causing plant diseases such as rusts and smuts. A few form mycorrhizal associations with trees, benefiting plant growth. E.g. *Agaricus*, *Amanita* (Mushrooms), *Polyporus* (Bracket fungi), *Puccinia* (Rusts), *Ustilago* (Smuts). This sub-division further divided into three classes. 1. Teliomycetes 2. Hymenomycetes 3. Gasteromycetes.

Class 1: Teliomycetes: This class primarily includes rust and smut fungi. These fungi are obligate or facultative plant parasites and are economically significant due to the diseases they

cause in crops. Most species are obligate parasites of higher plants, meaning they require a living host to complete their life cycle. They attack cereals, grasses, and other economically important plants. Unlike mushrooms and bracket fungi, Teliomycetes do not produce visible fruiting bodies (basidiocarps). Their spores develop as thick-walled resting spores (teliospores or chlamydospores). The teliospore is the key feature of this class and gives the group its name. Teliospores function as resting spores that later germinate to form basidia. Upon germination, teliospores produce a basidium on which basidiospores are formed. The basidium is often septate (divided into compartments), which differentiates them from other basidiomycetes. Many species have multiple spore stages, including: Urediniospores (repeating stage), Aeciospores (alternate host stage), Teliospores (resting stage), Basidiospores (infection stage). Some rust fungi require two different host plants to complete their life cycle (heteroecious fungi). Cause severe crop diseases, leading to reduced yield. E.g. Wheat rust (*Puccinia graminis*), Corn smut (*Ustilago maydis*). This class divides into two main orders. i) **Order: Uredinales** (Rust Fungi) - These fungi cause rust diseases in plants. They often have a complex life cycle with multiple hosts. Produce various types of spores, including urediniospores, aeciospores, teliospores, and basidiospores. E.g. *Puccinia graminis* (Wheat rust), *Melampsora lini* (Flax rust). 2. **Order: Ustilaginales** (Smut Fungi) - Smut fungi attack cereals and grasses, replacing host tissue with black, powdery teliospores. Unlike rust fungi, they generally have a simpler life cycle and do not require an alternate host. E.g. *Ustilago maydis* (Corn smut), *Tilletia indica* (Karnal bunt of wheat).

Class 2: Hymenomycetes: Hymenomycetes is a traditional class of Basidiomycotina that includes fungi with exposed basidia, forming basidiospores on a hymenium (fertile layer). It comprises mushrooms, bracket fungi, puffballs, coral fungi, and jelly fungi. These fungi are mostly saprophytic or mycorrhizal, with a few parasitic species. Basidia are arranged in a hymenium, a fertile layer covering the spore-bearing surface. The hymenium is often exposed at maturity, facilitating spore dispersal. Most species form large, visible fruiting bodies (basidiocarps), such as mushrooms and shelf fungi. Some have gelatinous or coral-like structures. The mycelium is well-developed, septate, and mostly dikaryotic (contains two genetically distinct nuclei per cell). The hyphae have dolipore septa, allowing selective cytoplasmic flow. Asexual reproduction is rare, though some species produce conidia. Sexual reproduction occurs via basidiospores, formed externally on club-shaped basidia. The spores are forcibly discharged and dispersed by wind. Many species are saprotrophs, decomposing wood, leaves, and organic matter. Some form mycorrhizal associations with plants, enhancing nutrient absorption. A few are parasitic, such as those causing white rot or root diseases in trees. E.g. Mushrooms: *Agaricus bisporus* (Edible mushroom), *Amanita phalloides* (Death cap); Bracket fungi: *Ganoderma lucidum* (Reishi), *Polyporus*; Jelly fungi: *Tremella*; Coral fungi: *Clavaria*. Hymenomycetes is divided into two major orders based on their basidiocarp structure and basidium type. i) **Order: Agaricales** (Gilled Fungi or Mushrooms) - Includes most mushrooms, toadstools, and gilled fungi. Basidiocarps are fleshy and umbrella-shaped, with gills (lamellae) on the underside. E.g. *Agaricus bisporus* (Button mushroom), *Amanita* (Poisonous mushrooms).

ii) **Order: Aphyllophorales** (Bracket Fungi, Coral Fungi, and Jelly Fungi) - Includes wood-decaying fungi, coral-like fungi, and jelly fungi. Fruiting bodies vary from leathery, woody, or gelatinous structures. E.g. *Ganoderma lucidum* (Reishi), *Tremella* (Jelly fungus), *Clavaria* (Coral fungus).

Class 3: Gasteromycetes: Gasteromycetes is a polyphyletic class of Basidiomycotina, historically recognized for fungi that produce their basidiospores internally rather than externally on an exposed hymenium. Unlike Hymenomycetes, where basidiospores develop on an exposed surface, in Gasteromycetes, spores mature inside a closed fruiting body (gasterocarp) and are only released when the structure breaks down or opens. This class includes puffballs, stinkhorns, earthstars, bird's nest fungi, and false truffles. Unlike other Basidiomycota, spores develop inside a completely enclosed fruiting body. The spores are released only when the fruiting body ruptures, decays, or is mechanically disturbed. Fruiting bodies are of various types i.e. Puffballs (*Lycoperdon*, *Calvatia*): Rounded, closed fruiting bodies that release spores in a puff when ruptured. Stinkhorns (*Phallus*, *Mutinus*): Foul-smelling fungi that attract insects for spore dispersal. Earthstars (*Geastrum*): Puffball-like fungi with outer layers that split open into a star shape. Bird's Nest Fungi (*Cyathus*, *Crucibulum*): Cup-like structures containing spore-filled "eggs" (peridioles). False Truffles (*Scleroderma*): Underground fruiting bodies similar to true truffles but tougher and inedible. Basidiospore dispersal mechanisms includes Passive dispersal - Many species release spores via wind, rain, or mechanical disturbance (e.g., puffballs). Insect mediated dispersal - Stinkhorns attract flies with their foul smell, which helps in spore distribution. Mycelium is septate and usually dikaryotic. The hyphae often have dolipore septa, like other Basidiomycota. Asexual reproduction is rare but can occur through conidia in some species. Sexual reproduction follows the standard Basidiomycota life cycle, but basidiospores develop within the fruiting body. These are mostly saprophytic nature and decomposing wood, leaf litter, and organic matter. Some are mycorrhizal, forming beneficial associations with plant roots. Some species are edible (*Lycoperdon, Calvatia*). Stinkhorns (*Phallus*) are considered medicinal in traditional Chinese medicine. Some species (*Scleroderma*) are toxic and resemble true truffles. This class includes various orders. i) **Order: Lycoperdales** (Puffballs and Earthstars) - fruiting bodies are globose or star-shaped. Spores are released through ruptured peridia (outer covering) or an apical pore. E.g. *Lycoperdon perlatum* (Common puffball), *Calvatia gigantea* (Giant puffball), *Geastrum triplex* (Earthstar fungus). ii) **Order: Phallales** (Stinkhorns) - foul-smelling fungi that attract insects for spore dispersal. Gleba (spore mass) is slimy and foul-smelling. E.g. *Phallus impudicus* (Common stinkhorn), *Mutinus caninus* (Dog stinkhorn). iii) **Order: Nidulariales** (Bird's Nest Fungi) - cup-like fruiting bodies resembling a bird's nest. Contains peridioles (egg-like structures) filled with spores. E.g. *Cyathus striatus* (Fluted bird's nest fungus), *Crucibulum laeve* (Smooth bird's nest fungus). iv) **Order: Sclerodermatales** (False Truffles) - fruiting bodies resemble truffles but are tough and inedible. Some form ectomycorrhizal relationships with trees. E.g. *Scleroderma citrinum* (Common earthball), *Pisolithus tinctorius* (Dye ball fungus, used in mycorrhizal inoculation).

Sub-division Deuteromycotina: This sub-division lacks a known sexual reproductive stage. This group is often referred to as Fungi Imperfecti because their sexual reproduction remains unknown, and they are classified based on their asexual (anamorphic) reproductive structures. No known sexual stage (teleomorph), though some may later be linked to Ascomycota or Basidiomycota. Asexual reproduction occurs mainly by conidia (asexual spores) produced on conidiophores. Hyphal structures are typically septate mycelium (divided by cross-walls), similar to ascomycetes. Nutrition is heterotrophic, generally saprophytic, parasitic, or symbiotic, playing roles in decomposition and diseases. Found in soil, decaying organic matter, and as pathogens of plants, animals, and humans. Includes species causing plant diseases (e.g., *Fusarium* wilt), human infections (e.g., *Candida* spp.), and antibiotic producers (e.g., *Penicillium* for penicillin). Since sexual reproduction is unknown, Deuteromycotina is classified based on conidial morphology and mycelial characteristics into three classes. 1. Blastomycetes 2. Hyphomycetes 3. Coelomycetes.

Class 1. Blastomycetes: Blastomycetes is an informal grouping within Deuteromycotina that consists of unicellular or yeast-like fungi. These fungi reproduce mainly by budding (blastoconidia formation) and lack a known sexual stage. Many species in this group are either saprophytic or pathogenic to humans and animals. Mostly exist as single cells rather than forming mycelium. Asexual reproduction occurs through the formation of blastoconidia (buds). No known sexual (teleomorphic) stage. Some species may later be reclassified under Ascomycota. Some species exhibit dimorphism, existing as yeasts at one temperature (e.g., 37°C) and as mycelial forms at lower temperatures (e.g., 25°C). Found in soil, decaying organic material, and as opportunistic pathogens in humans and animals. Some species cause diseases like blastomycosis, candidiasis, and cryptococcosis. This class includes three orders. i) **Order: Cryptococcales** - Yeast-like fungi with thick-walled blastoconidia. Often encapsulated, aiding in pathogenicity. E.g. *Cryptococcus neoformans* – causes cryptococcosis, primarily in immunocompromised individuals (e.g., AIDS patients). ii) **Order: Sporobolomycetales** – Yeast like fungi that may produce ballistoconidia (spores forcibly discharged). Found in soil and on plant surfaces. E.g. Sporobolomyces spp. – common saprophytic yeasts. iii) **Order: Saccharomycetales** (Previously in Deuteromycotina, now in Ascomycota). Includes yeast species that reproduce by budding. Many are economically important in fermentation. E.g. *Candida albicans* – causes candidiasis, an opportunistic fungal infection, *Saccharomyces cerevisiae* – used in brewing and baking.

Class 2: Hyphomycetes: Characterized by the production of **conidia on free or exposed conidiophores**. Conidiophores may be simple or branched, and conidia may be single or in chains. Many are important **plant pathogens or industrially useful fungi**. This class includes mainly two orders. i) **Order: Moniliales -** Conidia are produced singly or in chains on free conidiophores. The conidiophores are **not enclosed in fruiting structures**. **E.g. *Aspergillus* spp.** – includes species used in fermentation and food spoilage, ***Penicillium* spp.** – source of the antibiotic penicillin, ***Fusarium* spp.** – causes plant diseases such as *Fusarium* wilt, ***Trichoderma* spp.** – biocontrol agent against plant pathogens. ii) **Order: Dematiaceae (Melanconiales) -** Produces **darkly pigmented (melanized) conidia** on conidiophores. This order includes plant pathogens causing **leaf spots, cankers, and fruit rots**. **E.g. *Alternaria* spp.** – causes early blight in tomatoes and potatoes. ***Helminthosporium* spp.** – causes leaf spot diseases in cereals.

Class 3: Coelomycetes: These are primarily asexual fungi that produce conidia (asexual spores) inside specialized fruiting structures known as conidiomata. These structures are either: a) Pycnidia – flask-shaped fruiting bodies that enclose the conidia. b) Acervuli – flat, cushion-like fruiting bodies that erupt from host tissues. Many are plant pathogens, causing diseases in crops and trees. Some are saprophytic, living on decaying organic matter. E.g. *Colletotrichum* – causes anthracnose in various plants, *Phoma* – a plant pathogen affecting many crops, *Diplodia* – causes stem and fruit rots, *Phyllosticta* – responsible for leaf spot diseases. This includes two main orders. i) **Order: Sphaeropsidales -** conidia are formed in pycnidia, which are flask-shaped structures. E.g. *Phoma* spp. – causes root rot in plants. *Diplodia* spp. – associated with fruit and stem rot diseases. ii) **Order: Melanconiales -** conidia are produced in acervuli, which are cushion-like fruiting bodies. E.g. *Colletotrichum* spp. – causes anthracnose in many crops. *Gloeosporium* spp. – pathogens of fruit trees.

14.4 SUMMARY

The Ainsworth classification of fungi, proposed by Geoffrey Clough Ainsworth, is a hierarchical system that categorizes fungi based on morphology, reproduction, and phylogenetic relationships. Ainsworth's system, which evolved over time, was most notably outlined in *Ainsworth & Bisby's Dictionary of the Fungi*, and it classifies fungi into major groups corresponding to their reproductive structures and life cycles. The classification includes two main divisions **Myxomycota** (slime molds), and Eumycota (True Fungi). Myxomycota exhibit amoeboid and plasmodial stages. it is again divided into 4 classes i.e., Acrasiomycetes, Labyrinthlales, Myxomycetes and Plasmodiophoromycetes. The division Eumycota again divided in to 5 subdivisions i.e. **Mastigomycotina** (zoosporic fungi), which possess flagellated spores and include groups like Chytridiomycetes; **Zygomycotina** (zygomycetes), characterized by sexual reproduction via zygospores; **Ascomycotina** (ascomycetes), which produce sexual spores in sac-like asci; **Basidiomycotina** (basidiomycetes), forming spores externally on basidia; and **Deuteromycotina** (imperfect fungi), a group of fungi with no known sexual stage.

14.5 TECHNICAL TERMS

Aplanospore, Ascopore, Ascus, Basidiospores, Basidiomycetes, Cellulose, Chitin, Coenocytic, Oogamy, Perfect fungi, Phylogeny, Taxonomy.

14.6 SELF ASSESSMENT QUESTIONS

Q.1 Describe the salient features of important group of fungi
Q.2 Write in detail the classification of fungi given by Ainsworth.
Q.3 Define the characteristic features of Division Mycota
Q.4 Describe any recent system of classification of fungi giving its important characteristic features.
Q.5 Describe the salient features of sub- division Myxomycotina and Eumycotina.

14.7 SUGGESTED READINGS

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LESSON – 15

IMPORTANCE OF FUNGI IN AGRICULTURE AND INDUSTRY

OBJECTIVE OF THE LESSON

By studying this lesson students will understand the role of fungi in agriculture and industries. The significance of edible and poisonous mushrooms and mycotxins and their impact on agriculture and humans will be understood.

STRUCTURE OF THE LESSON

15.1 INTRODUCTION

Fungi play a vital role in agriculture, influencing soil health, crop productivity, and disease management. These microorganisms contribute to nutrient cycling, enhance plant growth through symbiotic relationships, and help control pests and diseases. Beneficial fungi, such as mycorrhizal fungi and decomposers, improve soil fertility and support plant development by increasing nutrient and water uptake. Additionally, some fungi act as natural biocontrol agents against plant pathogens and insect pests, reducing the need for chemical pesticides. However, fungi can also be detrimental, causing serious crop diseases, post-harvest spoilage, and mycotoxin contamination, leading to significant economic losses. Understanding and managing the role of fungi in agriculture is essential for sustainable farming practices, ensuring food security, and minimizing environmental impact. By harnessing the benefits of fungi while mitigating their harmful effects, farmers can enhance agricultural productivity in an eco-friendly and cost-effective manner. Fungi play a crucial role in various industries due to their ability to

produce valuable enzymes, antibiotics, organic acids, and fermented products. In the food and beverage industry, fungi like *Saccharomyces cerevisiae* are essential for baking, brewing, and winemaking, while *Aspergillus* and *Penicillium* species are used in cheese production and food preservation.

In pharmaceuticals, fungi serve as sources of antibiotics like penicillin and immunosuppressants such as cyclosporine. They are also employed in biotechnology for enzyme production, biofuel generation, and waste management. Additionally, fungi contribute to agriculture by producing biopesticides and biofertilizers, enhancing crop yield and soil health. Their diverse applications make fungi indispensable in modern industries. Yeast is a crucial microorganism with significant roles in food, beverage, and biotechnology industries. It is widely used in baking, where it ferments sugars to produce carbon dioxide, making dough rise. In brewing and wine making, yeast ferments sugars into alcohol and carbon dioxide, essential for beer, wine, and other alcoholic beverages. Additionally, yeast, particularly *Saccharomyces cerevisiae*, is employed in biotechnology for producing bioethanol, pharmaceuticals, and probiotics. It is also a rich source of vitamins, especially B-complex, and is used in nutritional supplements. Beyond industry, yeast serves as a model organism in scientific research, contributing to genetics, molecular biology, and medicine.

Mushrooms are classified into edible and poisonous varieties, with some being highly nutritious and others potentially deadly. Edible mushrooms, such as button mushrooms, shiitake, and oyster mushrooms, are rich in protein, vitamins, and antioxidants, making them a valuable addition to diets. However, many wild mushrooms, including the deadly Amanita species (e.g., Death Cap and Destroying Angel), contain potent toxins that can cause severe poisoning or even death. Some poisonous mushrooms resemble edible ones, making foraging risky without expert knowledge. Proper identification, sourcing from reputable suppliers, and avoiding wild mushrooms without confirmation from an expert are essential to ensure safety. Mycotoxins are toxic secondary metabolites produced by certain fungi, primarily *Aspergillus*, *Penicillium*, and *Fusarium* species, that contaminate food and feed crops. These toxins pose serious health risks to humans and animals, leading to acute poisoning or chronic diseases such as liver damage, immune suppression, and even cancer. Common mycotoxins include aflatoxins, ochratoxins, fumonisins, trichothecenes, and zearalenone. They can contaminate cereals, nuts, spices, fruits, and animal feed, especially under warm and humid conditions. Preventive measures include proper storage, drying, and food safety regulations to minimize contamination and exposure.

15.2 IMPORTANCE OF FUNGI IN AGRICULTURE

1. **Beneficial Roles of Fungi in Agriculture:** Fungi contribute positively to agriculture in several ways, including soil enrichment, plant growth promotion, and biological control.

a. **Soil Fertility and Nutrient Cycling:** Saprophytic fungi decompose plant and animal residues, breaking them down into simpler compounds, thus recycling nutrients and improving soil fertility. Fungal decomposition contributes to the formation of humus, which enhances soil structure and water retention. Some fungi, in symbiosis with plants or bacteria, help fix atmospheric nitrogen into a form usable by plants.

b. Mycorrhizal Fungi and Plant Growth Enhancement: Mycorrhizal fungi, such as arbuscular mycorrhizal (AM) fungi and ectomycorrhizal fungi, form symbiotic relationships with plant roots, improving phosphorus, nitrogen, and water absorption. Mycorrhizae enhance plant resistance to soil-borne pathogens by competing for nutrients and stimulating plant defense mechanisms. They help plants withstand drought stress by improving root absorption efficiency.

c. Biocontrol of Plant Diseases and Pests: Some fungi, such as *Trichoderma* species, act as biocontrol agents by suppressing soil-borne pathogens like *Fusarium*, *Rhizoctonia*, and *Pythium* through competition, antibiosis, and mycoparasitism. Entomopathogenic fungi, like *Beauveria bassiana* and *Metarhizium anisopliae*, infect and kill insect pests, reducing reliance on chemical pesticides.

d. Fungal Biofertilizers and Soil Improvement: Some fungi, such as *Aspergillus* and *Penicillium* species, release organic acids that solubilize phosphate, making it available to plants. Certain fungi enhance the availability of potassium and zinc in the soil, supporting plant growth.

e. Bioremediation and Waste Decomposition: Fungi help in the breakdown of agricultural pollutants, including pesticides and heavy metals, reducing soil contamination. Fungi accelerate the decomposition of agricultural waste, producing compost that enhances soil health.

2. Detrimental Roles of Fungi in Agriculture: While fungi offer many benefits, some species can cause significant agricultural problems.

a. **Plant Pathogens and Crop Diseases:** Fungi are responsible for a majority of plant diseases, leading to reduced yields and economic losses. Root and stem rots Caused by fungi like *Fusarium*, *Pythium*, and *Rhizoctonia*. Leaf and fruit diseases such as powdery mildew (*Erysiphe* spp.), downy mildew (*Plasmopara viticola*), and apple scab (*Venturia inaequalis*) are caused due to fungi. The Rust fungi (*Puccinia* spp.) and smut fungi (*Ustilago* spp.) infect cereals like wheat and corn, reducing grain quality. Fungi such as *Aspergillus* and *Penicillium* cause spoilage of stored grains, fruits, and vegetables.

b. **B. Mycotoxin Contamination:** Certain fungi produce toxic secondary metabolites called mycotoxins, which can contaminate crops and pose health risks to humans and livestock. Aflatoxins: Produced by *Aspergillus flavus* in peanuts, maize, and other crops. Fumonisins: Produced by *Fusarium* species in maize. Ochratoxins: Produced by *Penicillium* and *Aspergillus* in cereals and coffee.

c. **C. Competition with Crops:** Some fungi form symbiotic relationships with invasive weeds, promoting their growth and reducing crop productivity. Some soil fungi compete with crops for essential nutrients, affecting plant growth.

3. **Application of Fungi in Sustainable Agriculture:** Farmers and researchers are harnessing fungi to improve agricultural sustainability and reduce dependence on synthetic chemicals.

a. **Use of Mycorrhizal Inoculants:** Farmers use mycorrhizal fungi inoculants to improve plant growth, especially in degraded soils. Mycorrhizae are widely used in organic agriculture to reduce the need for chemical fertilizers.

b. **B. Development of Biopesticides and Biofungicides:** *Trichoderma* for disease control used as a biopesticide to combat fungal pathogens. Entomopathogenic fungi applied in integrated pest management (IPM) programs to control insect pests naturally.
c. **C. Fungal-Based Biofertilizers:** Phosphate-Solubilizing Fungi**:** Used to enhance phosphorus availability in the soil. Fungi like *Pleurotus* spp. are used to accelerate composting processes.

15.3 INDUSTRIAL APPLICATIONS OF FUNGI

Fungi have a wide range of industrial applications across multiple sectors, including food production, pharmaceuticals, biotechnology, agriculture, and environmental management. Their ability to produce enzymes, antibiotics, organic acids, and other bioactive compounds makes them essential in many industries. Below is a detailed account of their industrial uses:

1. **Food and Beverage Industry:** Fungi play a crucial role in food production, particularly in fermentation processes.

   a. Fermentation and Food Processing

   Bread-making: *Saccharomyces cerevisiae* (baker's yeast) is used in bread-making to ferment sugars, producing carbon dioxide that causes dough to rise.

   Alcohol production: Fungi, especially yeasts (*Saccharomyces cerevisiae*), are essential in brewing beer, fermenting wine, and distilling spirits.

   Cheese production: Specific fungal species, such as *Penicillium roqueforti* and *Penicillium camemberti*, are used in ripening blue cheese and Camembert cheese, giving them distinct flavors

   Soy sauce and miso production: *Aspergillus oryzae* is used to ferment soybeans in the production of soy sauce, miso, and sake.

   b. Edible and Cultivated Mushrooms

   Commercially grown mushrooms: Species such as *Agaricus bisporus* (button mushroom), *Lentinula edodes* (shiitake), and *Pleurotus ostreatus* (oyster mushroom) are cultivated for food.

   Mycoprotein production: *Fusarium venenatum* is used to produce Quorn™, a high-protein meat substitute.

2. **Pharmaceutical Industry:** Fungi are a major source of antibiotics, immunosuppressants, and other pharmaceutical compounds.

   a. Antibiotic Production

   Penicillin: *Penicillium notatum* and *Penicillium chrysogenum* produce penicillin, one of the first and most widely used antibiotics.

   Cephalosporins: Produced by *Acremonium* (formerly *Cephalosporium*), these antibiotics are used to treat bacterial infections.

   Erythromycin and Tetracycline precursors: Some fungi contribute to the biosynthesis of these antibiotics.

b. Immunosuppressants and Other Drugs

Cyclosporine: Derived from *Tolypocladium inflatum*, it is used in organ transplant patients to prevent rejection.

Statins: *Aspergillus terreus* produces lovastatin, which is used to lower cholesterol levels.

c. Antifungal and Anticancer Compounds

Griseofulvin: Produced by *Penicillium* species, it is used to treat fungal infections.

Ergot Alkaloids: *Claviceps purpurea* produces ergot alkaloids, which are used in migraine treatments (e.g., ergotamine) and as precursors for drugs like LSD.

3. **Biotechnology and Enzyme Production:** Fungi are excellent producers of industrial enzymes used in various sectors.

a. Enzyme Production

Amylases: *Aspergillus oryzae* and *Aspergillus niger* produce amylases, which are used in baking, brewing, and starch processing.

Cellulases: Used in biofuel production, paper processing, and textile industries, these enzymes break down cellulose into glucose.

Proteases: *Aspergillus* species produce proteases used in detergent manufacturing and leather processing.

Lipases: Used in dairy, detergent, and biodiesel industries to break down fats.

b. Biotechnological Applications

Genetic Engineering: Yeasts like *Saccharomyces cerevisiae* are used as model organisms for recombinant DNA technology.

Bioethanol Production: Fungi help ferment biomass into bioethanol, a renewable fuel.

4. **Agriculture and Pest Control:** Fungi are used as biopesticides and soil enhancers.

a. Biopesticides

***Beauveria bassiana*:** Used as a biological insecticide against pests like aphids and beetles.

***Metarhizium anisopliae*:** Effective against mosquitoes and other insect pests.

***Trichoderma* spp.:** Used as a biocontrol agent against plant pathogens.

b. Soil Improvement and Fertilization

Mycorrhizal Fungi: Enhance plant growth by improving nutrient absorption.

Composting and Decomposition: Fungi help break down organic matter into nutrient-rich compost.

5. **Environmental and Industrial Waste Management:** Fungi contribute to waste management and pollution control.
   a. **Bioremediation**
      Oil Spill Cleanup: *Aspergillus* and *Penicillium* species can break down hydrocarbons in crude oil spills.

      Heavy Metal Removal: Fungi absorb and detoxify heavy metals from industrial wastewater.

      Plastic Degradation: Some fungi, like *Pestalotiopsis microspora*, can break down polyurethane plastics.

   b. **Waste Recycling**
      Paper Industry: Fungal enzymes help break down lignin in paper pulp processing.

      Agricultural Waste Processing: Fungi are used to convert crop residues into valuable biofuels and animal feed.

6. **Textile, Leather, and Detergent Industry:** Fungi-derived enzymes contribute to sustainable textile and leather processing.
   a. **Textile Industry**
   Bleaching Agents: Fungal enzymes are used to produce eco-friendly fabric bleaches.

   Bio-stoning: Cellulases derived from fungi help in bio-stoning denim fabric.

   b. **Leather Industry**
   Tanning Processes: Fungal proteases help in softening leather.

   Eco-friendly Dye Production: Fungi produce natural dyes for textiles.

   c. **Detergent Industry:** Fungal Enzymes used in laundry detergents to break down stains and improve cleaning efficiency.

7. **Paper and Pulp Industry:** Fungi assist in pulp processing and paper recycling.
   Lignin Degradation: White-rot fungi like *Phanerochaete chrysosporium* degrade lignin, improving pulp quality.

   Enzymatic Bleaching: Reduces chemical use in paper bleaching.

8. **Cosmetics and Personal Care**
   Citric Acid Production: *Aspergillus niger* is used to produce citric acid, which is a common ingredient in cosmetics.

   Hyaluronic Acid: Used in skincare products, derived from fungal fermentation.

   Pigments and Dyes: Fungi produce natural colors used in cosmetics.

9. **Construction and Material Science:** Fungi are being explored for sustainable building materials.
   Mycelium-Based Materials: Used to make biodegradable packaging, insulation, and even fungal bricks.

   Fungal Biomaterials: Used as an alternative to plastic and Styrofoam.

15.4 IMPORTANCE OF YEASTS

Yeasts are single-celled fungi belonging to the kingdom Fungi, primarily classified under the phylum Ascomycota. Notable species include *Saccharomyces cerevisiae* (baker's yeast) and *Candida albicans* (a pathogenic yeast). Yeasts reproduce asexually through budding and are facultative anaerobes, capable of both aerobic respiration and anaerobic fermentation. Their versatility makes them invaluable across industries, ecosystems, and scientific research. Yeasts are single-celled fungi that play crucial roles in various natural and industrial processes. They have been used by humans for thousands of years in food production, medicine, and biotechnology. Their importance extends to ecosystems, where they contribute to nutrient recycling and symbiotic relationships. This paper discusses the various roles and applications of yeasts in detail.

Importance in Food and Beverage Production

Baking: *Saccharomyces cerevisiae* ferments sugars, producing CO_2, which leavens bread dough. Enzymes in yeast break down starches, enhancing flavor and texture.

Brewing and Winemaking: Yeasts convert glucose into ethanol and CO_2. *S. cerevisiae* (ale) and *S. pastorianus* (lager) determine flavor profiles in beer. Indigenous or cultured yeasts (e.g., *S. cerevisiae*) influence terroir and aroma to wine. Yeast fermentation precedes distillation for products like whiskey and vodka.

Fermented Foods: Traditional products like Kombucha (symbiotic culture of bacteria and yeast), kefir, and soy sauce can be made by fermentation. In d**airies y**easts contribute to the texture and flavor of cheeses (e.g., Camembert).

Biotechnology and Industrial Applications

Bioethanol Production: Yeasts ferment plant-derived sugars (e.g., corn, sugarcane) into ethanol, a renewable fuel additive.

Pharmaceuticals: Recombinant DNA technology in *S. cerevisiae* yields human insulin. Vaccines like Hepatitis B and HPV vaccines use yeast-expressed viral proteins.

Recombinant Protein Synthesis: Yeasts produce enzymes (e.g., invertase), therapeutics (e.g., interferons), and industrial proteins.

Environmental Roles

Decomposition and Nutrient Cycling: Yeasts degrade organic matter in soil, releasing nutrients (e.g., nitrogen) for plant uptake.

Symbiotic Relationships: Enhance root nutrient absorption and protect against pathogens via mutualistic interactions.

Insects: Assist in digesting complex sugars in insect guts (e.g., termites, beetles).

Health and Medicine

Pathogenic Yeasts: *Candida albicans* causes infections (e.g., thrush, systemic candidiasis), particularly in immunocompromised individuals.

Therapeutic Uses: As probiotics, *Saccharomyces boulardii* treats antibiotic-associated diarrhea. In drug production yeasts are used E.g. Yeast-derived antifungals (e.g., amphotericin B) and vitamins (B-complex).

Scientific Research: Yeasts used as model organisms in pioneering studies on cell cycle regulation, apoptosis, and autophagy. Study on sequencing of yeast genome aids in understanding human diseases (e.g., cancer). CRISPR - Yeast facilitated homologous recombination techniques, foundational for gene-editing technologies. Yeast Two-Hybrid System - identifies protein-protein interactions.

Other Applications: Yeast used as nutritional supplements to the Vegans as a source of B vitamins and protein. Yeast extract is rich in umami flavor (used in Marmite/Vegemite). Yeast extracts used in skincare products to promote hydration and anti-aging (e.g., β-glucans).

15.5 EDIBLE AND POISONOUS MUSHROOMS

Mushrooms have been a part of human history for thousands of years, serving as a source of food, medicine, and even spiritual enlightenment. However, while some mushrooms offer immense nutritional and medicinal benefits, others pose significant risks due to their toxic properties. This essay aims to provide a detailed examination of edible and poisonous mushrooms, discussing their characteristics, benefits, dangers, and methods of identification to help foragers and consumers make informed decisions. Mushrooms belong to the fungi kingdom and play crucial roles in ecological systems. They decompose organic matter, recycle nutrients, and contribute to soil health. Edible mushrooms, such as the common button mushroom (*Agaricus bisporus*), provide valuable nutrients like proteins, vitamins, minerals, and antioxidants. Poisonous mushrooms, on the other hand, contain toxic compounds that can lead to severe illness or even death.

Edible Mushrooms: Edible mushrooms are cultivated and harvested worldwide for their culinary and medicinal properties. Some of the most well-known edible mushrooms include:

1. **Button Mushroom (*Agaricus bisporus*):** The most commonly consumed mushroom. Available in white and brown forms. Rich in protein, B vitamins, and antioxidants.
2. **Shiitake (*Lentinula edodes*):** Popular in Asian cuisine. Contains compounds that support immune function and cardiovascular health.
3. **Portobello (*Agaricus bisporus*):** A mature version of the button mushroom. Used in grilling and stuffing due to its meaty texture.
4. **Oyster Mushroom (*Pleurotus ostreatus*):** Grows in clusters on trees or logs. Contains compounds with potential cholesterol-lowering effects.
5. **Chanterelle (*Cantharellus cibarius*):** Recognized for its golden color and fruity aroma. A favorite in gourmet dishes.

6. **Morel (*Morchella spp.*):** Highly sought after for its unique texture and flavor. Requires thorough cooking to remove mild toxins.
7. **Lion's Mane (*Hericium erinaceus*):** Known for its potential cognitive benefits. Used in both culinary and medicinal applications.

Nutritional Benefits: Mushrooms are low in calories but rich in protein, fiber, vitamins (B, D), and minerals (selenium, potassium). They contain antioxidants like ergothioneine, linked to reduced inflammation and chronic disease prevention.

Poisonous Mushrooms: Many toxic mushrooms closely resemble edible varieties, making identification crucial. Some of the most dangerous poisonous mushrooms include:

1. **Death Cap (*Amanita phalloides*):** Responsible for most mushroom poisoning fatalities worldwide. Contains amatoxins that cause liver and kidney failure.
2. **Destroying Angel (*Amanita virosa, Amanita bisporigera*):** Resembles edible white mushrooms but is highly toxic. Symptoms appear hours after ingestion and lead to organ failure.
3. **Panther Cap (*Amanita pantherina*):** Contains potent neurotoxins. Causes hallucinations, seizures, and coma.
4. **Fly Agaric (*Amanita muscaria*):** Known for its bright red cap with white spots. Contains psychoactive compounds that can cause nausea, confusion, and delirium.
5. **False Morel (*Gyromitra spp.*):** Resembles true morels but contains gyromitrin, a toxic compound. Can cause severe neurological and liver damage.
6. **Deadly Webcap (*Cortinarius rubellus*):** Causes irreversible kidney damage. Often mistaken for edible mushrooms.
7. **Jack O'Lantern (*Omphalotus olearius*):** Resembles chanterelles but glows in the dark. Causes severe gastrointestinal distress.

Toxins and Health Impacts

Amatoxins: Cause liver failure; treatment requires activated charcoal and N-acetylcysteine.
Orellanine: Found in *Cortinarius* spp., induces kidney failure over days.
Muscarine: In *Clitocybe* and *Inocybe* spp., triggers excessive salivation, sweating, and blurred vision.

Identification and Safety Measures: Foragers must take extreme caution when harvesting wild mushrooms. Here are some tips for safe identification:

1. Consult Experts: Seek guidance from experienced mycologists or use reliable field guides.
2. Examine Physical Traits: Observe color, shape, gill structure, and spore print. Poisonous Amanitas have white gills and a volva (cup-like base).
3. Avoid Mushrooms with White Gills and Rings: Many toxic mushrooms, such as the Death Cap, have these features.
4. Test with a Spore Print: Place the mushroom cap on paper to reveal spore color. Color varies (e.g., white for deadly Amanitas vs. pink for edible Agaricus).
5. When in Doubt, Leave It Out: If unsure, do not consume the mushroom.
6. Habitat: Morels grow near dying trees, while Galerina thrives on decaying conifers.

Look-Alikes and Pitfalls

1. **False Morels** (*Gyromitra*) **vs. True Morels**: *Gyromitra* has irregular, brain-like caps vs. honeycombed morels.
2. **Chanterelles vs. Jack-O'-Lanterns** (*Omphalotus olearius*)**:** The latter glows bioluminescent and grows in clusters.

Effects of mushroom poisoning: Mushroom poisoning symptoms vary based on the type of toxin. Common symptoms include: Gastrointestinal distress - Vomiting, diarrhea, and abdominal pain. Neurotoxicity - Hallucinations, confusion, and seizures. Hepatotoxicity - Liver failure caused by amatoxins. Nephrotoxicity - Kidney failure leading to long-term damage.

Treatment of mushroom poisoning: Immediate medical attention is crucial in cases of suspected poisoning. Steps to take include: Do not induce vomiting - Seek emergency medical care immediately. Identify the mushroom - Provide a sample to medical professionals. Activated Charcoal - May help absorb toxins if taken early. Hospitalization - Severe cases require intensive treatment, including liver transplants.

15.6 MYCOTOXINS

Mycotoxins are toxic secondary metabolites produced by certain species of fungi (molds) that can contaminate food, feed, and agricultural products. They pose significant health risks to humans and animals, causing acute and chronic diseases, including cancer, immune suppression, and organ damage. Mycotoxins are primarily produced by *Aspergillus*, *Penicillium*, *Fusarium*, and *Claviceps* species, among others.

Types of Mycotoxins: Several mycotoxins have been identified, but the most significant ones in terms of health and economic impact include:

1. Aflatoxins: These are produced by *Aspergillus flavus* and *Aspergillus parasiticus.* Commonly found in grains (corn, wheat, rice), peanuts, tree nuts, spices, and milk (as aflatoxin M1). Aflotoxins are having Hepatotoxic (liver damage), carcinogenic (causes liver cancer), immunosuppressive, and teratogenic (causes birth defects) effects. Aflatoxin levels are strictly regulated worldwide due to their high toxicity, with the FDA setting limits for food and feed.

2. Ochratoxins: These toxins produced by *Aspergillus ochraceus*, *Aspergillus carbonarius*, and *Penicillium verrucosum.* Commonly found in cereals, coffee, dried fruits, wine, beer, and pork. These are having Nephrotoxic (kidney damage), hepatotoxic, carcinogenic, neurotoxic, and immunosuppressive nature. Ochratoxin A has to be regulated in foodstuffs, particularly in Europe, to limit exposure.

3. Fumonisins: These are produced by *Fusarium verticillioides* and *Fusarium proliferatum.* Commonly found in corn and corn-based products. These are having neurotoxic, hepatotoxic, nephrotoxic, and associated with esophageal cancer in humans; causes leukoencephalomalacia (brain softening) in horses.

4. Trichothecenes (e.g., Deoxynivalenol, T-2 Toxin, HT-2 Toxin): Produced by *Fusarium* species. Commonly found in **c**ereal grains (wheat, barley, oats, rye, and corn). These toxins

inhibits protein synthesis, causes vomiting, immune suppression, diarrhea, hemorrhaging, and neurological issues.

5. Zearalenone: Produced by *Fusarium* species. Commonly found in corn, wheat, barley, and other cereals. These are having Estrogenic effects (mimics estrogen), causing reproductive disorders in animals (infertility, abortion, feminization in males).

6. Ergot Alkaloids: Produced by *Claviceps purpurea* (ergot fungus). Commonly found in Rye and other cereal grains. These are having toxic effects like vasoconstriction, gangrene, hallucinations, convulsions (ergotism or "St. Anthony's Fire").

Factors influencing mycotoxin production: Mycotoxin production by fungi is influenced by various environmental, biological, and substrate-related factors. These factors can determine the type and amount of mycotoxins produced. Key factors include:

1. Environmental Factors

Temperature: Mycotoxin production varies with temperature. Aflatoxins (produced by *Aspergillus flavus*) thrive in warm conditions (25–35°C). Ochratoxins (produced by *Penicillium* and *Aspergillus* species) are produced at lower temperatures (10–30°C).

Moisture and Water Activity (aw): High humidity and water activity (>0.7) promote fungal growth and mycotoxin synthesis. Grains stored in moist conditions are more susceptible.

Oxygen Levels: Aerobic conditions favor mycotoxin production. Modified atmosphere storage (low oxygen, high CO_2) can reduce fungal growth.

pH Levels: Most toxigenic fungi prefer slightly acidic to neutral pH (4–7).

2. Biological Factors

Fungal Strain: Different strains of the same species produce varying amounts of mycotoxins.

Competition with Other Microorganisms: Bacteria, yeasts, and non-toxigenic fungi can inhibit toxin-producing fungi.

Genetic Regulation: Some fungal genes control mycotoxin biosynthesis, which may be activated or suppressed by environmental conditions.

3. Substrate and Nutritional Factors

Type of Crop or Food Source: Grains (corn, wheat, peanuts) are highly susceptible to aflatoxin contamination. Coffee beans and grapes can contain ochratoxins.

Nutrient Availability: High carbohydrate and nitrogen content favor fungal growth and mycotoxin production.

Presence of Stress Factors: Drought, insect damage, and improper storage conditions increase vulnerability to mycotoxin contamination.

4. Agricultural and Post-Harvest Practices

Pre-Harvest Conditions: Drought stress and high temperatures increase toxin accumulation.

Storage Conditions: Poor ventilation and high humidity encourage fungal growth.

Processing Methods: Some mycotoxins can survive food processing (e.g., roasting, cooking).

5. Chemical and Physical Stressors

Pesticides and Fungicides: Some fungicides may inhibit fungal growth but not always prevent mycotoxin production.

UV Light and Radiation: UV exposure can degrade some mycotoxins but may also stress fungi to produce more toxins.

Health Effects of Mycotoxins: Exposure to mycotoxins can cause acute poisoning or chronic diseases, depending on the dose and duration of exposure. Major health effects include: **Liver cancer** (Aflatoxins), **Kidney damage** (Ochratoxins), **Neurotoxicity** (Fumonisins), **Hormonal disruption** (Zearalenone), **Immune suppression** (Trichothecenes, Aflatoxins, Ochratoxins). Mycotoxins can enter the human food chain through contaminated plant-based foods, contaminated animal products (meat, eggs, and dairy), and water.

Detection: Fungal toxins can be determined Chromatographic techniques (HPLC, LC-MS, ELISA (Enzyme-Linked Immunosorbent Assay), Biosensors and Spectroscopic methods.

Prevention and Control: We can prevent and control the fungal toxins by using following practices.

1. **Good Agricultural Practices (GAP):** Proper crop rotation, use of resistant varieties, and avoiding drought stress
2. **Good Storage Practices:** Keeping grains dry and cool to prevent mold growth.
3. **Chemical and Biological Detoxification:** Use of mycotoxin binders in animal feed, ozone treatment, and enzymatic degradation
4. **Regulations and Monitoring:** Governments set maximum allowable limits in food and feed, with rigorous testing

15.7 SUMMARY

Fungi play a crucial role in agriculture by enhancing soil fertility, promoting plant growth, and contributing to disease control. Mycorrhizal fungi form symbiotic relationships with plant roots, improving nutrient and water absorption, which boosts crop yields. Decomposer fungi break down organic matter, recycling essential nutrients into the soil. Some fungi, such as *Beauveria bassiana* and *Trichoderma* species, act as natural biopesticides, helping control harmful pests and plant diseases, reducing the need for chemical pesticides. Additionally, fungi like *Penicillium* are used in post-harvest preservation to prevent spoilage. However, certain pathogenic fungi can also cause significant crop losses, making fungal disease management essential in agriculture.

Fungi play a crucial role in various industrial applications, including pharmaceuticals, food production, biotechnology, and biofuel generation. They are widely used in the production of antibiotics (e.g., *Penicillium* for penicillin), immunosuppressants, and cholesterol-lowering drugs. In the food industry, fungi contribute to the fermentation of bread, beer, wine, and cheese, with species like *Saccharomyces cerevisiae* being essential for yeast fermentation. Industrial enzymes derived from fungi, such as cellulases and amylases, are used in textiles, detergents, and biofuel production. Additionally, fungi are employed in bioremediation to degrade pollutants and in agriculture as biofertilizers and biopesticides. Their diverse metabolic capabilities make them invaluable across multiple industries.

Yeast is a crucial microorganism with widespread applications in food, beverage, and biotechnology industries. It plays a vital role in fermentation, enabling the production of bread, beer, wine, and other fermented foods by converting sugars into carbon dioxide and alcohol. In baking, yeast helps dough rise, giving bread its texture and flavor. In the medical field, certain yeast strains are used in probiotic supplements and pharmaceutical research, including vaccine development. Additionally, yeast serves as a model organism in genetic studies, contributing to scientific advancements in cell biology and biotechnology. Its versatility makes it indispensable in both traditional and modern industries.

Edible mushrooms, such as button mushrooms (*Agaricus bisporus*), chanterelles (*Cantharellus cibarius*), and porcini (*Boletus edulis*), are widely consumed for their rich flavors and nutritional benefits, including vitamins, minerals, and antioxidants. However, some mushrooms are highly toxic and can be fatal if ingested. Poisonous species like the death cap (*Amanita phalloides*), destroying angel (*Amanita virosa*), and the fly agaric (*Amanita muscaria*) contain harmful toxins that can cause severe organ damage or neurological symptoms. Proper identification is crucial, as some toxic mushrooms closely resemble edible varieties, making foraging risky without expert knowledge.

Mycotoxins are toxic compounds produced by certain fungi that can contaminate food and animal feed, posing serious health risks. These toxins, including aflatoxins, ochratoxins, fumonisins, and trichothecenes, are commonly found in crops like grains, nuts, and coffee when stored under warm, humid conditions. Exposure to mycotoxins can lead to acute poisoning or long-term health effects such as liver damage, immune suppression, and even cancer. While food safety regulations and proper storage methods help minimize contamination, mycotoxins remain a global concern, particularly in regions with inadequate food monitoring and control measures.

15.8 TECHNICAL TERMS

Mold, Pathogen, Yeast, Mycorhiza, Aflotoxins, Biopesticides, Mycotoxins

15.9 SELF ASSESSMENT QUESTIONS

Q.1 Write an essay on agricultural importance of fungi.
Q.2 Describe the industrial applications of fungi.
Q.3 Explain the importance of yeast.
Q.4 Write an account on edible and poisonous mushrooms.
Q.5 Describe the mycotoxins.

15.10 SUGGESTED READINGS

1. Microbiology, Michael J. Pelezer, J.R., E.C.S. Chan, Noel R. Krieg (1993) - Indian Edition(5thEdition), Mc Graw Hill Education (India) Private Limited.
2. Botany for Degree Students Part II FUNGI, B. R. Vashishta, (1990), S. Chand & Company LTD. Ram Nagar, New Delhi 110055.
3. Botany for Degree Students, B. P. Pandey, (2015). As per UGC Model Curriculum.

Prof. A. Amruthavalli

LESSON - 16

GENERAL CHARACTERISTICS OF PROTOZOA

OBJECTIVE OF THE LESSON

To enlighten the students about the protozoa and their important features like classification, morphology, nutrition and reproduction.

STRUCTURE OF THE LESSON

16.1 INTRODUCTION

The study discipline of protozoa [S., protozoan; Greek *protos*, first and *zoon*, animal] is called protozoology. Protozoans are microscopic and unicellular animalcules, without tissues, having one or more nuclei, some shows macro-and micronucleus. They exist either single or in colonies which differ from a metazoan in having all the individuals alike except when engaged in reproductive activities. Protozoa grow in a wide variety of moist habitats and they absolutely require moisture for their existence as they are susceptible to desiccation. Most protozoa are free living and inhabit fresh water or marine environments. Many terrestrial protozoa can be found decaying organic matter, and some are parasitic in plants and animals. Protozoa are the protists exhibiting heterotrophic nutrition and various types of locomotion. Protozoa usually reproduce asexually by binary fission. Some have sexual reproduction, involving meiosis and the fusion of gametes resulting in the formation of a diploid zygote. In some protozoa, conjugation may occur in which nuclei are exchanged between cells.

16.2 CLASSIFICATION OF PROTOZOA

Many of the protozoan taxonomists regard Protozoa as a sub-kingdom, which contains seven of the 14 phyla found within the kingdom Protista. The classification of this sub-kingdom into phyla is based primarily on types of nuclei, mode of reproduction, and mechanism of locomotion. Based on the 1980 committee on Systematics and Evolution of the Society of Protozoologists, the protozoa are placed in seven phyla.

Phylum Sarcomastigophora

Protists that have a single type of nucleus and possess flagella (subphylum Mastigophora) or pseudopodia (subphylum Sarcodina) are placed in this phylum. Both sexual and asexual reproduction are present in the members of this phylum. The subphylum, Mastigophora contains both phytoflagellates, chloroplast-bearing flagellates and close relatives, and zooflagellates. The zooflagellates do not have chlorophyll and are holozoic, saprozoic, or symbiotic. Asexual reproduction occurs by longitudinal binary fission along the major body axis. Sexual reproduction is known to occur in some species, and encystment is common. Zooflagellates are characterized by the presence of one or more flagella. Most members are uninucleate. The kinetoplastids, one major group of zooflagellates, has its mitochondrial DNA in a special region called the kinetoplast. The most representative form is *Trypanosoma* species (Figure 16.1). Some zooflagellates are free living and many are important human parasites. The subphylum, Sarcodina contains the amoeboid protists. They occur throughout the world, both fresh and salt water forms and are abundant in soils. Several species are parasites of mammals, but many are free living forms. *Amoeba*, is the typical example of this subphylum and well known for its aboeboid movement (Figure 16.2). Many have no definite shape, and their internal structures occupy no particular position. The single nucleus, contractile and phagocytic vacuoles, and ecto- and endoplasm shift as they move. Amoebae engulf a variety of materials like small algae, bacteria, other protozoa through phagocytosis. Through pinocytosis, some materials move in and out of the plasma membrane. Reproduction is by simple asexual binary fission and some can also form cysts. Some amoebae are symbiotic and live in other animals.

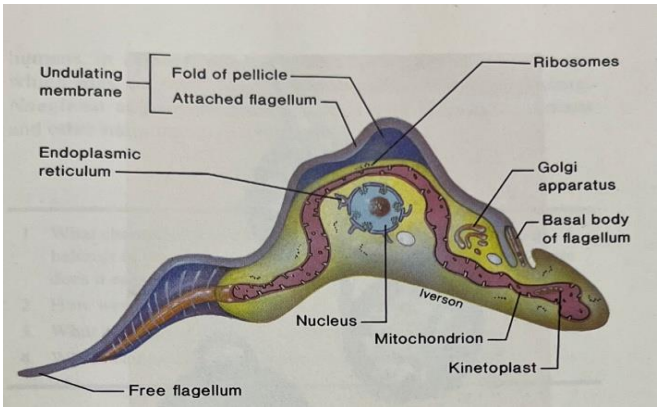

Figure-16.1: Structure of the flagellate (Trypanosoma sp.)
(Source: Microbiology – Prescott et. al.)

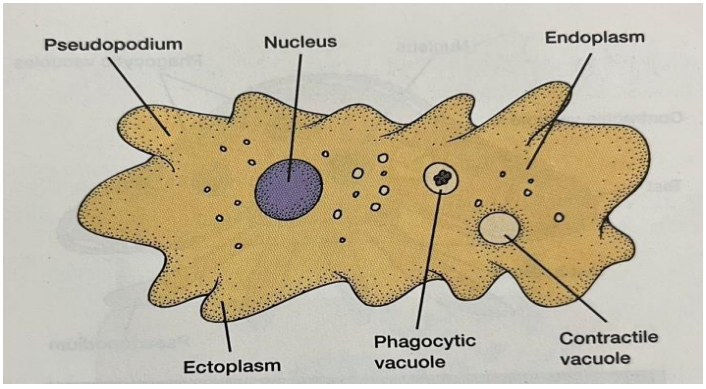

Figure-16.2: Structure of the amoeboid protist (*Amoeba proteus*)
(Source: Microbiology – Prescott et. al.)

Phylum Labyrinthomorpha

It is a small phylum consisting of protists with spindle-shaped or spherical, non-amoeboid vegetative cells. In some genera, amoeboid cells move within a network of mucous tracks using a typical gliding motion. Most members of this phylum are marine and either saprozoic or parasitic on algae.

Phylum Apicomplexa

The members (apicomplexans) are often called as sporozoans, have a spore-forming stage in their life cycle and lack special locomotary organelles (except in the male gametes and the zygogte or ookinete). They are either intra- or intercellular parasites of animals and are distinguished by a unique arrangement of fibrils, microtubules, vacuoles, and other organelles, collectively called as the apical complex that is located at one end of the cell. The apical complex contains polar rings, pellicle, sub-pellicular tubules, conoid, rhoptries and micropore (Figure 16.3). Apicomplexans have complex life cycles in which certain stages occur in one host (mammal) and other stages in a different host (mosquito). The life cycle possess both asexual and sexual phases and is characterized by an alternation of haploid and diploid generations.

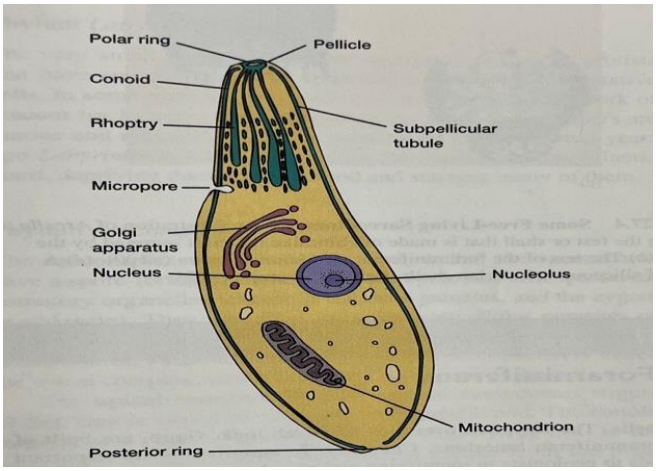

Figure-16.3: Structure of an apicomplexan sporozoite
(Source: Microbiology – Prescott et. al.)

Phylum Microspora

The microsporans are small (3 to 6 µm) and obligatory intracellular parasites lacking mitochondria. The infective stage is transmitted from host to host as a resistant spore. Several protozoan species of some economic importance are included in this phylum as they parasitize beneficial insects. There is an increased interest in these parasites because of their possible role as biological control agents for certain insects. For example, *Nosema locustae* has been approved and registered by the United States Environmental Protection Agency for use in long-lasting control of rangeland grasshoppers. Recently some microsporidian genera (*Nosema*, *Encephalitozoon*, *Pleistophora*, *Microsporidium*, *Vittaforma*, *Trachipleistophora* and *Enterocystozoon*) have been implicated in human diseases in immunosuppressed and AIDS patients.

Phylum Ascetospora

Ascetospora is relatively a small phylum that consists exclusively of parasitic protists characterized by the spores lacking polar caps or polar filaments. Ascetosporians such as *Haplosporidium* are parasitic primarily in the cells, tissues, and body cavities of mollusks.

Phylum Myxozoa

The myxozoans are all parasitic mostly on freshwater and marine fish. They possess resistant spores with one to six coiled polar filaments. The most economically important myxozoan is *Myxosoma cerebralis* that infects the nervous system and auditory organ of salmonids. The infected fish lose their sense of balance and tumble erratically which is known as tumbling disease.

Phylum Ciliophora

Ciliophora is the largest of the seven protozoan phyla consisting of about 8,000 species. Although most ciliates are free living, symbiotic forms also exist. Some ciliated protozoa live as harmless commensals (*Entodinium* – found in rumen of cattle; *Nyctotherus* - occurs in colon of frogs). Some ciliates are strict parasites (*Balantidium coli* lives in intestine of mammals). *Ichthyophthirius* lives in fresh water and attack many fish species causing a disease known as 'ick'. These are unicellular, heterotrophic protists that range from about 10 to 3,000 µm long. Ciliates employ many cilia as locomotory organelles and are generally arranged in longitudinal rows or in spirals around the body of the organism. The ciliates show a great variation in their shape. The *Paramecium* is slipper shaped (Figure 16.4); *Vorticella* attaches itself to the substrate by a long stalk. The *Stentor* attaches to a substrate and stretches out in a trumpet shape during feeding. A few members have tentacles to capture the prey, while some discharge toxic thread-like darts (toxicysts) and use them to capture the prey. Most striking feature of ciliates is their ability to capture many particles in a short time by the action of the cilia around the buccal cavity. Most of the ciliates have two types of nuclei – a large macronucleus and a smaller micronucleus. Some ciliates reproduce asexually by transverse binary fission forming two equal daughter protozoa. Many ciliates also reproduce by conjugation. Some details of the classification of the subkingdom Protozoa are presented in table 16.1.

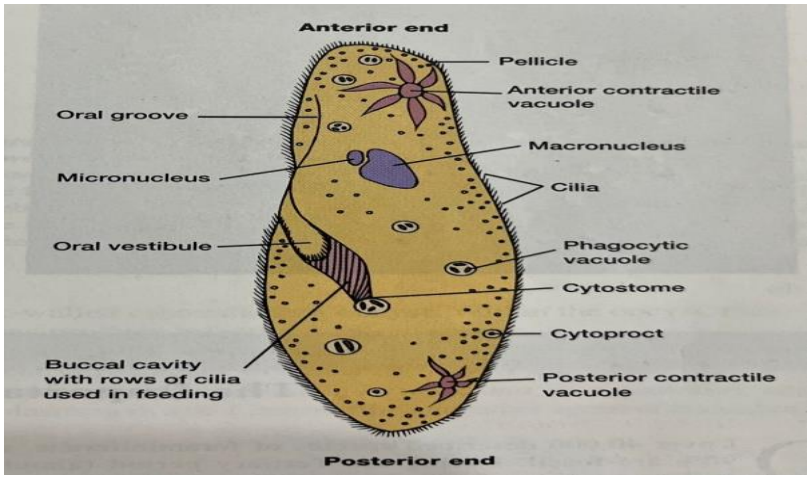

Figure-16.4: Structure of the ciliate (*Paramecium caudatum*)
(Source: Microbiology – Prescott et. al.)

Table-16.1: Classification of the Subkingdom Protozoa

Taxonomic Group	Characteristics	Examples
Phylum: *Sarcomastigophora*	Locomotion by flagella, pseudopodia, or both; when present, sexual reproduction is essentially syngamy (union of gametes external to the parents); single type of nucleus	
Subphylum: *Mastigophora*	One or more flagella; division by longitudinal binary fission; sexual reproduction in some groups	
Class: *Zoomastigophorea*	Chromatophores absent; one to many flagella; amoeboid forms, with or without flagella; sexuality known in some groups; mainly parasitic	*Trypanosoma* *Giardia* *Trichomonas* *Leishmania* *Trichonympha*
Subphylum: *Sarcodina*	Locomotion primarily by pseudopodia; shells (tests) often present; flagella restricted to reproductive stages when present; asexual reproduction by fission; mostly free living	
Superclass: *Rhizopoda*	Locomotion by pseudopodia or by protoplasmic flow with discrete pseudopodia; some contain tests	*Amoeba* *Elphidium* *Coccodiscus*
Phylum: *Labyrinthomorpha*	Spindle-shaped cells capable of producing mucous tracks; trophic stage as ectoplasmic network; nonamoeboid cells; saprozoic and parasitic on algae and seagrass	*Labyrinthula*
Phylum: *Apicomplexa*	All members have a spore-forming stage in their life cycle; contain an apical complex; sexuality by syngamy; all species parasitic; cysts often present; cilia absent; often called the Sporozoa	*Plasmodium* *Toxoplasma* *Eimeria* *Cryptosporidium*
Phylum: *Microspora*	Unicellular spores with spiroplasm containing polar filaments; obligatory intracellular parasites	*Nosema*
Phylum: *Ascetospora*	Spore with one or more spiroplasms; no polar capsules or polar filaments; all parasitic in invertebrates	*Haplosporidium*
Phylum: *Myxozoa*	Spores of multicellular origin; one or more polar capsules; all parasitic, especially in fish	*Myxosoma*
Phylum: *Ciliophora*	Simple cilia or compound ciliary organelles in at least one stage in the life cycle; two types of nuclei; contractile vacuole present; binary fission transverse; sexuality involving conjugation; most species free living, but many commensal, some parasitic	*Didinium* *Stentor* *Vorticella* *Tetrahymena* *Paramecium* *Tokophrya* *Entodinium* *Nyctotherus* *Balantidium* *Ichthyophthirius*

[a]Based on the 1980 Committee on Systematics and Evolution of the Society of Protozoologists.

(Source: Microbiology – Prescott et. al.)

16.3 STRUCTURE OF PROTOZOAN CELL

Size and form

Most of the protozoa are microscopic. The size ranges from a few thousandth of a millimeter to a millimeter in length. Some of the smallest protozoans are *Babesia, Leishmania* and *Plasmodium*. Some protozoa like *Paramecium* are large enough to be seen with the naked eye. Protozoa vary widely in their form. Some are asymmetrical (*Amoeba*), radial symmetry is seen mostly in sessile forms (*Vorticella*), bilateral symmetry is limited to a few protozoa (*Giardia*) and spherical symmetry (*Radiolaria*).

Body covering and skeleton

In Protozoa, the cytoplasm remains separated from the external environment by a cell envelope. This covering protects the body from harmful influences of outer environment, permits a controlled exchange of substances across it, perceives mechanical and chemical stimuli and establishes contact with other cells. It may take the following types.

Plasmalemma

In some forms, the body covering is a thin plasma membrane or plasmalemma. It is provided with longitudinal ridges of mucopolysaccharides which help in the adhesion of organism to the substratum. e.g., *Amoeba* (Figure 16.5A)

Pellicle

In some protozoans, the body covering is in the form of a differentiated pellicle, which is some- what thicker and firm. In some forms the pellicle is ridged and sculptured.
Example: *Paramecium*, *Coleps* (Figure 16.5B)

Skeletal layers

Some other protozoa display various secreted layers, often impregnated with foreign bodies. These constitute the protozoa skeleton and include cyst, theca, lorica and test or shell.

(a) Cyst: It is a temporary sheath, and is formed both in free living and parasitic protozoa. Exhaustion of food supply, drought and putrefaction favour encystment.

(b) Theca: It is a coat of closely fitted armour of cellulose layer. In some forms the theca is composed of two valves, while in a majority of dinoflagellates (e.g. *Ceratium, Glenodinium*) differentiated into a number of plates laid out in a definite pattern (Figure 16.5C)

(c) Lorica: It is a covering, which fits less closely to the organism than theca. It is a cup like or vase like structure with an opening through which emerges the anterior part of organism's body or its appendages. In colonial loricated forms, one lorica may be attached to another directly (e.g. *Dinobryon*) or by means of a stalk (e.g. *Peteriodendron*, Figure 16.5D)

(d) Shell or Test: These are common among protozoa. These coverings are loose contact with the body, provided with one or more openings, through which the animal can protrude itself. In shelled amoebae, like *Arecella* and allied forms, the shell is thin and made up of a chitinous material called pseudochitin (Figure 16.5E)

In *Difflugia* (Figure 16.5F) shells are formed of sand particles and other foreign substances like pieces of foraminifers are mostly made up of calcium carbonate. In *Euglepha* (Figure 16.5H) silicious shells are made up of silica.

(e)Radiolarian Skeleton: Continuous internal skeleton is found in radiolarians. The skeleton lies in between the ectoplasm and endoplasm forming the so-called central capsule. The capsule is made up of pseudochitin or silica or strontium sulphate. One or a few or many pores perforate it. In many radiolarians the skeleton consists of a lattice network, which is variously sculptured and ornamented. (Figure 16.5 I, J, K).

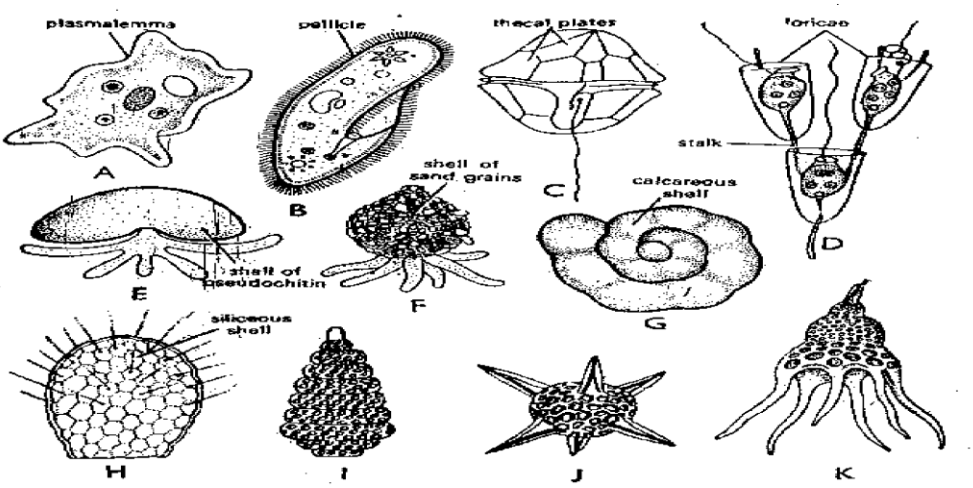

Figure-16.5: Protozoan skeletons. A. plasmalemma of *Amoeba*, B- Pellcle of *Paramecium*,

C- Thecal plates of *Glenodinum*. D- Lorica of *Peteriodendron*, E- Pseudochitinous shell of *Arcella*, F- Sand grain shell of *Difflugia*. G- Calcarious shell of *Discorbis*. H- Silicious shell of *Euglepha*. I- K – Radiolarion skeletons.

(https://www.slideshare.net/slideshow/protozoa-pptx-microscopic-eukaryotes-unicellular/271790110)

Cytoplasm

Cytoplasm consists of the peripheral ectoplasm and central endoplasm. In certain protozoa, the differentiation between these two areas is indistinct. The endoplasm includes endoplasmic reticulum, ribosomes, lysosomes, microtubules, centrioles, plastids, flagella, cilia etc. Other structures like trichocysts, contractile vacuoles, stigmas etc., which are exclusive of protozoa, are seen in certain individuals.

Nucleus

All protozoans possess nuclei. Some have one, others have two or more identical nuclei (E.g. Mastigophora, Sarcodina and Sprorozoa). But some others have two types of nuclei- macronucleus and micronucleus. Micronucleus takes an active part in sexual reproduction and macronucleus is associated with trophic or metabolic activities.

Locomotor Oraganelles

Locomotor organelles include pseudopodia, flagella, cilia and pellicular contractile structures.

Pseudopodia

These are temporary structures formed by the streaming flow of the cytoplasm. On the basis of the form and structure the pseudopodia are of the following types:

(a) Lobopodia: These are lobe- like pseudopodia with broad and rounded ends (*Amoeba*, Figure 16.6A).

(b) Filopodia: These are more or less filamentous pseudopodia, usually tapering from base to the pointed tip (*Euglypha*, Figure 16.6B)

(c) Reticuloppodia: These are branched filamentous and fuse profusely to form a net work (*Globigerina*, Figure 16.6C)

(d) Axopodia: These are more or less straight and radiating pseudopodia (*Actinophrys*, Figure 16.6D)

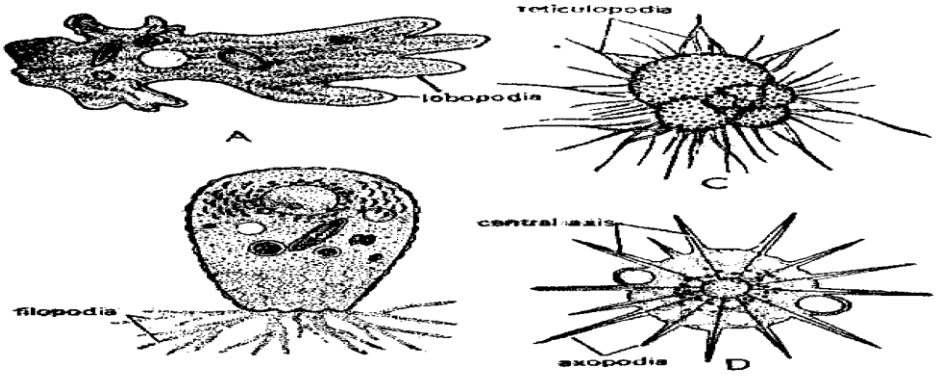

Figure-16.6: Types of pseudopodia. A- Lobopodia of *Amoeba* B- Filopodia of *Euglepha*. C- Reticulopodia of *Globigerina* D- Axopodia of *Actinophryis* sol.

(Courtesy https://examinationtyari.blogspot.com/2019/12/protozoa-characters-classification-and.html)

Flagella

These are thread like projections on the cell surface. A typical flagellum consists of an elongate shaft, the axoneme enclosed by an outer sheath. In the axoneme, nine longitudinal peripheral paired fiber form a cylinder, which surrounds the central longitudinal fibres enclosed by a membranous inner sheath. The axoneme ends at the base in a granule, called the blepharoplast.

Cilia

Cilia are highly vibratile small ectoplasmic processes. These resemble flagella in their basic structures.

Pellicular contractile structure

In many protozoa, the outer pellicle contractile structures are present called myonemes.

Regeneration

Most protozoa can regenerate their lost parts, as normally displayed at fission or encystment. Parasitic protozoa usually have slight regenerative capacity. Nucleus plays an important role in the process.

Encystment

Encystment occurs either during reproduction or during unfavorable periods such as drought, over population, lack of food and oxygen, accumulation of metabolic wastes in the cytoplasm and changes in the temperature and pH. Encystment serves for survival, protection and dispersal. In the encysted state, the animalcule suspends all its physiological activities and lies dormant. When the normal conditions are restored, the cyst takes up water and ruptures and the enclosed animalcule emerges to resume on active life once again.

16.4 REPRODUCTION IN PROTOZOA

Protozoans reproduce in two ways, asexual and sexual modes.

Asexual Reproduction

Protozoans exhibit different methods of asexual reproduction. They are:

(a) Binary Fission

In this, a single parent undergoes division and produces two daughter individuals. This division is not a mere fragmentation but a complicated process of mitosis. The fission may be either in a trans- verse plane (e. g. *Paramecium*) or in a longitudinal plane (e.g. *Euglena*) or in an oblique plane (e.g. *Ceratium*) or in any plane (e. g. *Amoeba*). The two daughter organisms produced as a result of binary fission carry all the cytoplasmic organelles of the parent individual. Some organelles like mitochondria, divide at the time of division others like oral apparatus, flagella and contractile vacuoles are formed afresh by one of the daughters (Figure-16.7A-D).

(b) Plasmotomy

It is a special type of binary fission concerned with the division of multinucleate protozoa into two or more smaller multinucleate daughter individuals (Figure-16.7B).

(c) Budding

Irregular fission resulting in a small daughter individual in the form of a bud. When the bud

breaks off it grows to full size. When a parental body produces only one bud it is monatomic (e.g. *Vorticella*). But in some others several buds are formed simultaneously, it is called multiple budding (e.g. *Suctoria*).

(d) Multiple Fission

In this the nuclear division is not followed immediately by the division of the cytoplasm. First the nucleus undergoes a series of divisions and becomes multi nucleate. Later the body cytoplasm divides into as many parts as there are daughter nuclei, which usually arrange themselves at the periphery each getting surrounded by a fragment of cytoplasm. Thus the parent body simultaneously divides into as many daughter individuals as there are nuclei. Multiple fission is quite common in *Foraminifera*, *Radiolaria*, *Sporozoa* and certain Mastigophora (Figure 16.8A)

(e) Schizogony

In this process a series of nuclear divisions results into numerous daughter nuclei. This is followed by the formation of cytoplasmic buds each containing a nucleus. The buds are pinched off to grow into new organisms (E. g. merozoites and sporozoites of *Plasmodium*).

(f) Endodyogeny

This consists in the development of two daughter individuals with in a single parent, which is destroyed in the process (e. g. *Toxoplasmea*)

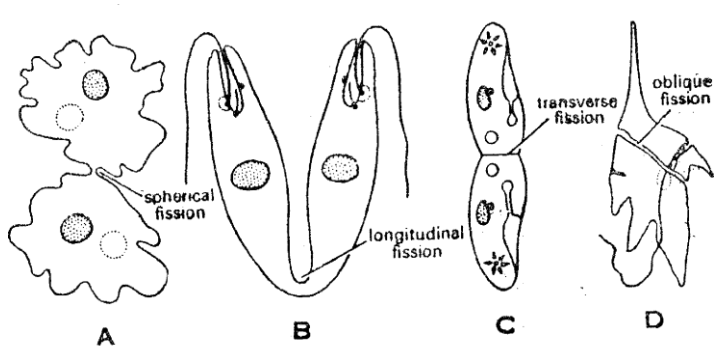

Figure-16.7: Binary fission in Protozoa. A- *Amoeba* (irregular) B-*Euglena*(longitudinal). C- *Paramesium* (Transverse) D- *Ceratium*(oblique)

(Source: Invertebrates— R.S. Kotpal)

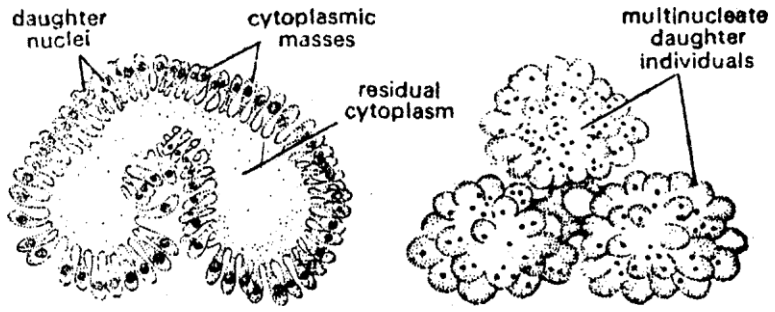

Figure-16.8: A- Multiple fission B- Plasmotomy.

Sexual reproduction

In protozoa, sexual reproduction occurs by the following processes:

(a) Syngamy

Syngamy is the complete fusion of two sex cells or the gametes, resulting in the formation of zygote. The zygote is called synkaryon. Depending upon the degree of differentiation displayed by the fusing gametes syngamy is of the following types.

(i) Hologamy

The two mature protozoan individuals do not form gametes but themselves behave as gametes and fuse together to form zygote. Hologamy occurs in a few Sarcodina and Mastigophora.

(II) Isogamy

The gametes similar in size and shape but differ in behavior are called isogametes and their union is called isogamy. It is common in *Foraminifera* and *Gregarina*.

(iii) Anisogamy

The fusion occurs between the two dissimilar gametes is called anisogamy. The small and motile gametes are the male or microgametes and the large non-motile ones are the female or macrogametes. It is widely seen in sporozoa.

(iv) Autogamy

It is the fusion of the gametes derived from the same parent cell as in *Actinophrys* and *Actinospherium*.

B.Conjugation

This involves fusion of two individuals and is characteristic of ciliates. In conjugation, the two ciliate individuals couple temporarily during meiosis with reciprocal cross- fertilization of their gametic nuclei. Conjugation can only takes place between individuals of the same syngen but belonging to opposite mating types. Several nuclear divisions take place during pre and post fertilization events of the conjugation and the whole phenomenon seems to initiate a new life cycle (Figure 16.9).

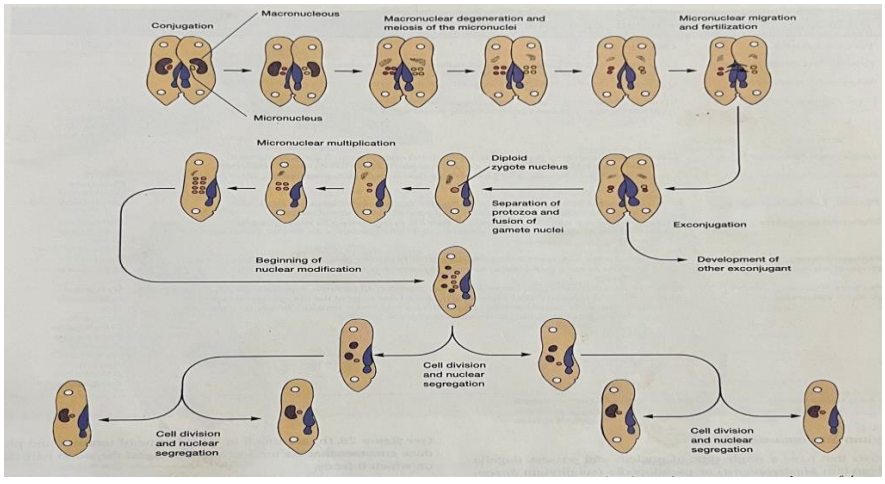

Figure-16.9: Schematic diagram of conjugation in *Paramecium caudatum*
(Source: Microbiology – Prescott et. al.)

C. Autogamy

In autogamy only one individual is involved, which displays the same nuclear behaviour as in conjugation. There is self-fertilization of the gametic nuclei. Autogamy ensures a sort of nuclear reorganization (*Paramecium aurelia*).

D. Cytogamy

This process is in between conjugation and autogamy. The two individuals do pair but the cross- fertilization of their gametic nuclei does not take place. The male gametic nuclei unite with the female gametic nucleus of the same individual.

E. Endomixis

It is an internal process of nuclear reorganization. It differs from conjugation in that it occurs only with in a single individual and there is no meiosis and fusion of gametic nuclei.

F. Hemixis

This involves an aberrant behaviour of macronucleus in a single individual. It is supposes to be a sort of purification act on the part of the macronucleus, which under goes degenerative changes independent of binary fission or syngamy.

16.5 SIGNIFICANCE

Several species of protozoa form highly virulent parasites of men and animals causing various dreadful infectious diseases particularly in the tropical countries. The knowledge of these parasites is useful from the medical point of view. The knowledge of portals of entry and the means of transmission of these parasites is of vital importance from the stand point of preventive medicines. With the discoveries of the alternation of generation, the host, the causes and modes of transmission of malaria, yellow fever, sleeping sickness and other diseases, the unexplored parts of the world have been exploited by the man, countless deaths have been prevented and the food supply has been increased enormously. Thus a general study of the phylum protozoa is most essential to understand the parasitic forms and to fight out their menace to mankind, domestic animals and crops.

Numerous aquatic forms feed upon bacteria and help in the purification of water. Indirectly they form the food of fish, clams and other animals, which are consumed by man. The success of fish culture depends upon a thorough knowledge of protozoa.

Useful Protozoa

(a) Helpful in Sanitation: Numerous holozoic protozoa feed on putrefying bacteria in various bodies of water and thus help indirectly in the purification of water. These protozoa play an important part in the sanitary betterment and the improvement of the modern civilized world in keeping water safe for drinking purpose.

(b) Planktonic Protozoa as Food: Protozoa floating in the plankton of sea provide directly or indirectly the source of food supply to man, fish and other animals. They form one of the first links in the numerous and complicated food chains that exists in the oceans of the world. Clams and young fish feed extensively on aquatic insect larvae, small crustaceans, and worms etc. all of which take protozoa as food. Thus protozoa indirectly form the food of fish, clams and other animals, which in their turn are consumed by man.

(c) Symbiotic Protozoa: Some protozoans are found in symbiotic relationship with other organisms. Most outstanding examples of symbionts are several intestinal flagellates (*Trycholympha, Colonympha*) of termites and wood roaches. These flagellates digest cellulose converting it into soluble glycogen substances for their host as well as for themselves.

(d) Oceanic Ooze and Fossil Protozoa: Tiny skeletons of dead pelagic Foraminifera, Radioloaria and Heliozoa sink to the sea bottom forming the soft mud on oceanic ooze. These tiny skeletons are made up of calcium carbonate or silica. Over countless millions of years these skeletons deposited on the floor of ocean became solid and fossilized and converted into some important sedimentary rock strata. These have commercial uses such as filtering agents, abrasives, chalk and building stones.

(e) Protozoa in Study: The protozoa are single celled individuals possessing forms and functions similar to cells of metazoans body. Individual cells from higher animals can be cultured only under carefully controlled, aseptic conditions, but protozoans only require a drop of water on a microscopic slide. Thus they can be used in experiments to illustrate the basic principles of the cell biology and zoology. The specificity of the host among parasitic protozoa provides clues regarding the phylogenetic relations of the host and also regarding the past geographical state of the earth.

Harmful Protozoa

(a) Soil Protozoa: Several species of protozoa, present in large numbers in soil, feed upon the nitrifying bacteria, and thus decline their activity and consequently tend to decrease the amount of nitrogen given to soil by the nitrifying bacteria.

(b) Water Pollution: Where as some protozoa are helpful in water sanitation, others become responsible for contamination or pollution. The protozoa of fecal origin belong to this latter category. Some free living protozoa (e.g. *Uroglenopsis*) also pollute water by producing aro- matic and oily secretions with objectionable odours, which render water unfit for human consumption. Some bioluminescent dinoflagellates, such as *Noctiluca, Gymnodinium, Gonyaulax*, living in sea, sometimes multiply so extensively as to turn the water red with their bodies. The phenomenon is known, as blooming and is the cause of red tides, often experienced in the sea. Out breaks of this red water often gives a foul and disagreeable odour to the ocean water. Large concentrations of these flagellate protozoans may even lead to destruction of fish and poisoning of edible molluscs, such as clams, oysters and mussels, etc. making then unfit for human consumption

(c) Pathogenic Protozoa: Some protozoa cause diseases in man (Figure 16.9) as well as in animals and these are termed pathogenic protozoa. They occur in all cases of protozoa.

(i) Pathogenic Sarcodines: There are two common genera of parasitic amoebae, entam- oeba and endamoeba, which live in the intestine of man and of other

animals. Only two species of *Entamoeba: E. histolytica* of man and other mammals and *E. invadens* of reptiles are known to be seriously pathogenic. *E. histolytica* is responsible for amoebic dysentery or amoebiasis in man, which occurs in about 60 to 70% Indian population.

E. invadens, occurring in the colon of reptiles, causes reptilian amoebiasis.

(ii) Pathogenic Flagellates: Pathogenic species of parasitic flagellates are included in the genera *Leishmania, Trypanosoma, Histomonas, Trichomonas* and *Giardia.* Three patho- genic species of *Leishmania* have been known to cause severe diseases in man. *L. donovani* causes kala- azar, a disease of the spleen and liver, *L. tropica* cause a peculiar type of skin lesion (cutaneous leishmaniasis) and *L. brasiliensis* causes infection of nasopharynx and skin lesion. These are transmitted by sand flies of the genus *Phlebotomus*, Parasitic species of *Trypanosoma* in mammals cause worst diseases. *T. gambiense,* is the causative agent of fatal African sleeping sickness. *T. rhodesiense, T. cruzi, T. equiperdum, T. evansi,* and *T. brucei* are other common pathogenic species. *Histomonas meleagridis* is the parasitic mastigamoeba. Of the parasitic species of *Trichomonas, T.vaginalis* is the causative organism of vaginal trichomoniasis or vaginitis in human females. *T. foetus* causes trichomoniasis of cattle in U.S and *T. gallinae* is pathogenic in doves, pigeons, turkeys and chickens. Of the numerous species of *Giardia: G. intestinalis (= G. lamblia)* of man causes enterocolitis.

(iii) Pathogenic Sporozoans: Protozoan super class Sporozoa is exclusively of parasitic forms. Though most of sporozoans are harmless, yet some genera like *Plasmodium, Eimeria, Isospora* and *Babesia* include pathogenic species. Species of *Plasmodium* are called malaria parasites as they cause the disease of malaria. Four species of *Plas- modium,* namely *P. vivax, P. malariae, P. ovale* and *P. falciparum* cause malaria in man. Malaria is caused by *P. cyanomolgi* in monkeys, by *P. verghei* in tree rats and by *P. gallinaceum* in jungle fowl of Asia. Pathogenic species of *Eimeria* cause coccidiosis in chickens and rabbits. *E. tenella* and *E. mitis* infect chicken whereas *E. mana* and *E. steidae* infect rabbits. *E. canis* in dogs, *E. felina* in cats, *E. bovis* in cattle and *E. intricata* in sheep and goats are also common. *Isospora*, intestinal parasites of man and other animals, include one truly pathogenic species of man, *I. hominis, I.felis, I. bigemina* and *I. riolta* infect cats and dogs and occur in mucous membranes of ileum. Their transmission is by cylindrical oocysts. Species of *Babesia* are intra- erythrocytic para- sites of various vertebrates. *Babesia bigemina* of cattle causes the lethal haemoglobinuric fever, red- water fever or Taxas fever. *B. equi* in horses, *B. rohdani* in rodents, *B. felis* in cats, *B. motasi* in goats, etc. cause malignant jaundice, anaemia and fever in their respective hosts.

(iv) Pathogenic Ciliates: *Balantidium coli* is the only important ciliate pathogenic parasite. It is found in the intestine of man and often in frogs.

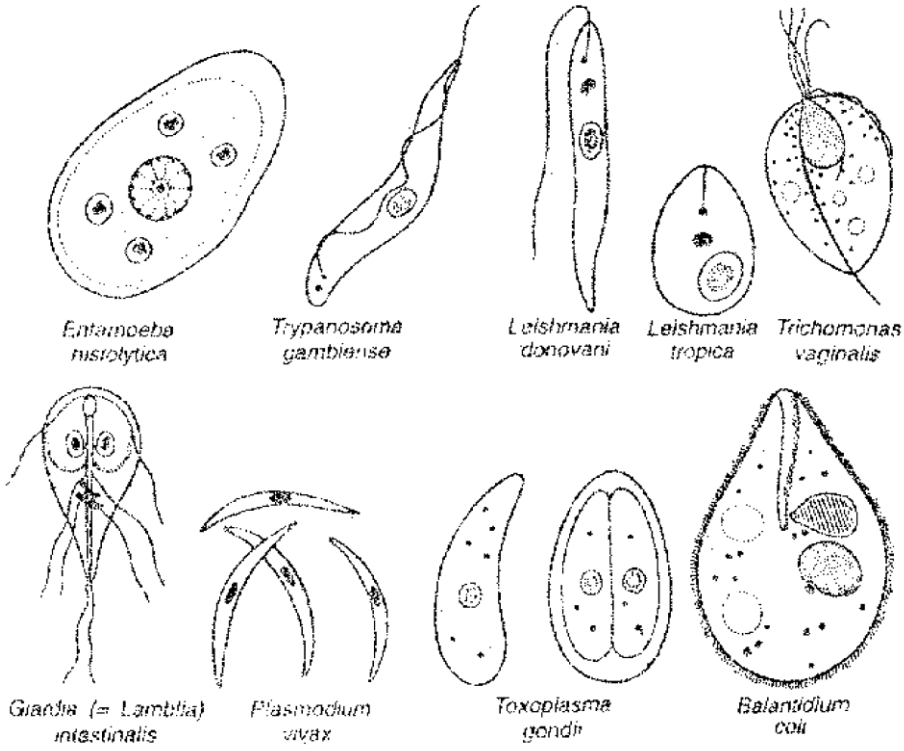

Figure-16.9: Some pathogenic protozoan parasites of man.

16.6 SUMMARY

Protozoa is the earliest and the simplest of unicellular group of animals. Some are free living and some parasitic. Single cell performs all the body functions. Protozoa is divided into five classes on the basis of locomotory organelles. Mastigophora have flagella. Sarcodina possess pseudopodia. No locomotion in Opalinata and sporozoa. Which are parasitic and cilia are present in ciliates. Body naked or covered by a pellicle or plasmalemma or rigid dead cuticle or calcarious or silicious shell. Skeleton usually absent but some forms have internal supporting elements like internal shell. Body consists of a mass of protoplasm, differentiate into one or more nuclei and ecto- and endoplasm. The functions of locomotion and feeding are performed by finger like pseudopodia or whip like flagella or hair like cilia. Nutrition is varied in these animals. It may be holozoic, holophytic, saprophytic, parasitic or myxotrophic. Digestion is intra cellular, taking place inside the cell in the food vacuoles. Reproduction is both asexual and sexual. The former takes place by binary or multiple fission and budding while the later takes place by conjugation. Several species of protozoa form highly virulent parasites of men and animals causing various dreadful infectious diseases. Numerous aquatic forms feed upon bacteria and help in the purification of water. Indirectly they form the food of fish, clams and other animals, which are consumed by man.

16.7 TECHNICAL TERMS

Axopodium, Bilateral symmetry, Endoskeleton, Parasitism, Pathogenic, Radial symmetry.

16.8 SELF ASSESSMENT QUESTIONS

Q.1 Mention the chief types of locomotor organelles of protozoa.

Q.2 Write an essay on

a. Protozoa and human diseases
b. Body coverings and skeletons in protozoa.

Q.3 Give a brief account of the modes of reproduction in protozoa.

Q.4 Name some important pathogenic species of protozoa that cause diseases in man.

16.8 SUGGESTED READINGS

1. Invertebrates - R. S. KOTPAL, 8th Edi., Rastogi publications, 2001.
2. Microbiology- Prescott *et. al.*, III Edi., Wm. E. Brown publishers, 2000.

Dr. J. Madhavi

LESSON – 17

PROTOZOA GENERA - ENTAMOEBAAND TRYPANOSOMA

OBJECTIVE OF THE LESSON

Students will learn the detailed characteristic features of Entamoeba and Trypanosomagenera and their medical importance.

STRUCTURE OF THE LESSON

17.1 INTRODUCTION

Amoebiasis, also called as amoebic dysentery, is a parasitic infection caused by protozoan Entamoebahistolytica. Geographically it is estimated that up to 15% of the world's population is infected by the pathogen E.histolytica. Every year, over 1,00,000 people die of the disease caused by E. histolytica. Generally amoebiasis is passed to human beings from fresh water contaminated with human faeces. The majority of amoebiasis cases occur in developing countries and industrialized countries. Risk groups include men who have sex with men, travelers, recent immigrants, immune compromised persons and institutionalized populations and this is the second most common parasitic cause of death, after malaria.

African trypanosomiasis, also known as African sleeping sickness or simply sleeping sickness, is an insect-borne parasitic infection of humans and other animals. It is caused by the species Trypanosomabrucei. Humans are infected by two types, Trypanosomabruceigambiense (TbG) and Trypanosomabruceirhodesiense (TbR). TbG causes over 98% of reported cases.Both are usually transmitted by the bite of an infected tsetse fly and are most common in rural areas.

17.2 ENTAMOEBA

17.2.1 Entamoebahistolytica

Taxonomically, Entamoebahistolytica, belongs to Phylum - Amoebozoa, Class -Lobosea, Order - Amoebidaand Family -Entamoebidae.

Morphology

E. histolytica is a typical unicellular protozoan. The cells are spherical to oval, 20-40 µm in diameter. It possesses a central nucleus and cytoplasm is clearly seen as outer more denseectoplasm and inner endoplasm. Cell membrane is thin and elastic. It shows amoeboid movements with elongated pseudopodia which may be suddenly protruded and retracted. They feed on intestinal bacteria, mucins, RBCs etc. The cells transform into cysts under unfavorable condition. Cysts are thick walled, spherical resting structure of 10-20 µm in diameter. Immature cyst is uninucleate. As it matures nucleus divides twice to become quadrinucleate.E.histolytica is differentiated into 18 zymodemes which are distinguished and recognized basing on electrophoretic mobility of one or more enzymes. Of the 18 types, only 7 are potentially pathogenic and 11 are non- pathogenic.

Life Cycle and Pathogenesis

The active, invasive, and pathogenic stage of E. histolytica is referred to as Trophozoite (magna form) and the smaller, precystic stage that can be found in the intestinal lumen is referred as Minuta (Figure 17.1). Infection occurs by ingestion of mature cysts. Cysts are very resistant and can survive outside the body for long periods and are transmitted through contaminated food, particularly raw vegetables, fruits and water. Ingested quadrinucleate mature cysts survive passage through stomach and reach small intestine. Excystation occur in the lower region of small intestine. The emerging protoplast, called metacyst or primary trophozoite, divides rapidly to produce 8 uninucleatetrophozoites. These trophozoites begin feeding on mucous and intestinal bacteria, and move to the large intestine or colon, (Figure-17.2) where they remain confined to the intestinal lumen (non-invasive infection) and can invade the host tissue causing the disease or live as commensals in the lumen of the intestine or undergo encystations with individuals continuing to pass cysts in their stool (asymptomatic carriers). Trophozoites passed in the stool or rapidly destroyed once outside the body and if ingested would not survive exposure to gastric environment. The behavior of trophozoites in the colon depends upon the strains and host resistance.

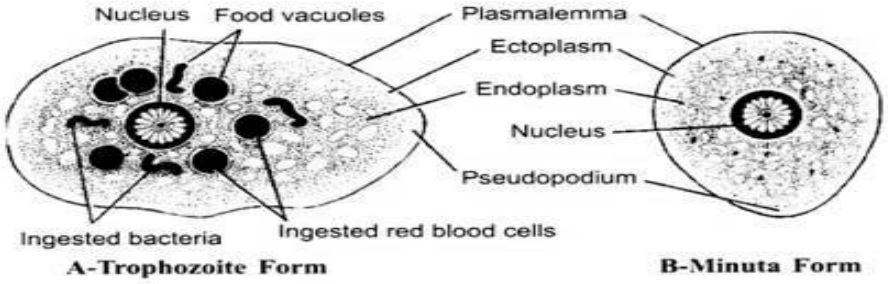

Figure-17.1:EntamoebahistolyticaTrophozoite form and precyst form
(Courtesy by https://www.waterpathogens.org/node/9160)

The pathogenic strains invade the intestinal tissues, multiply rapidly and spread to deeper tissues of intestinal wall, by producing cytotoxins and proteolytic enzymes. Necrotic lesionsor amoebic abscesses are formed on the intestinal wall due to invasion of the pathogen. Sometimes amoeboma, a tumor like mass develop in the wall of large intestine. The irritating effect of the amoeba on the cell lining the intestine cause intestinal cramps and diarrhea. Due to intestinal lesions or ulcers, the diarrheal fluid is often bloody and the condition is reffered to as dysentery. The severity of the disease is directly related to the extent of invasion and ulceration of intestinal wall.

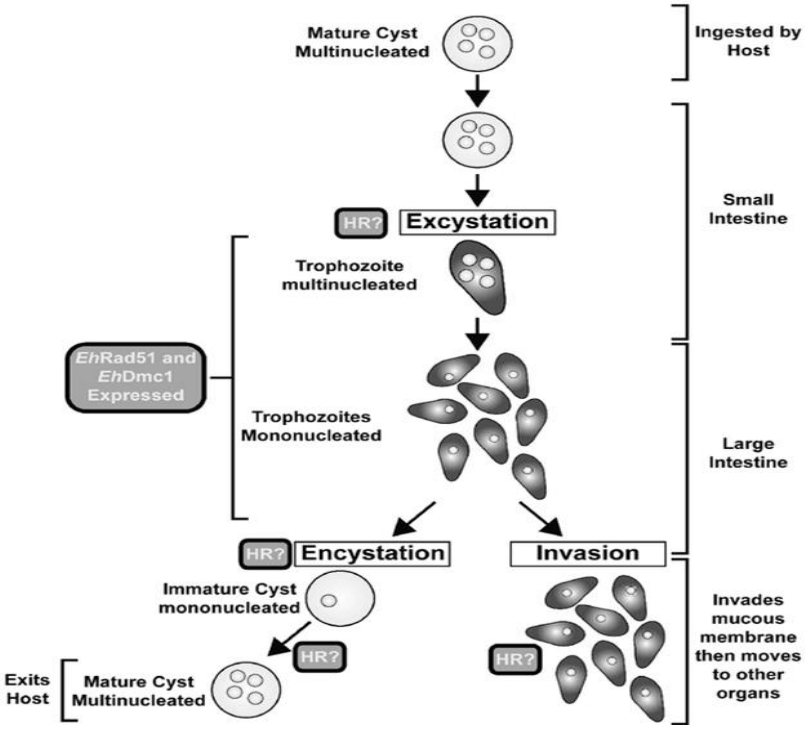

Figure-17.2:Entamoebahistolytica.

Excystation and trophozoite formation occurs in small intestine. Trophozoites that enter large intestine may 1. Invade the host tissue, or 2. Live in the lumen of large intestine without invasion, or 3. Undergo encystation and pass out of the host.

(Courtesy by https://www.researchgate.net/figure/Life-Cycle-of-Entamoeba-histolytica-The-human-host-ingests-the-mature-cyst-The-cyst_fig3_319572670)

The pathogen may also invade and produce lesions in extra- intestinal foci, especially liver to cause hepatic amoebiasis. It occurs through hematogenous spread of the pathogen. The pathogen may also spread to lungs. However, all extra-intestinal amoebic lesions are secondary to ones established in the large intestine.

Other species of Entamoeba

Entamoebagingivalis

Entamoebagingivalis is a non-pathogenic human parasite. It was the first parasite amoebae reported from man and was discovered by Gross in 1849.E. gingivalisis commonly known as mouth amoeba. It lives in the cavities of teeth, in the tarter and plaque deposited around the base of teeth. It may also live in the abscesses of gums and pus-pockets of tonsils.The subsphericaltrophozoite of E. gingivalis measure 12 to 20 mm in diameter. It bears 2 or 3 small and blunt (i.e., broad and rounded) pseudopodia, called lobopodia. The cytoplasm is divisible into a dear homogeneous peripheral ectoplasm and central, granular, highly vacuolated endoplasm.Endoplasm contains a vesicular nucleus with central endosome and several food vacuoles.Trophozoites havepseudopodial locomotion. It feeds mainly on bacteria present in the cellular debris around the roots of teeth and also on white blood cells (WBC) by phagocytosis.Trophozoite reproduces only by asexual means, i.e., by binary fission. It does not form cysts and is transmitted from mouth to mouth of persons either by contact during kissing or while eating or drinking by same utensils.Its occurrence is more common in mouth of persons suffering from pyorrhoea. E. gingivalis is known to aggravate pyorrhoea disease by destroying the gum tissues.

Entamoeba coli

Entamoeba coliis the commonest species of Entamoeba found in the colon and has been stated to occur probably in 50% of human population. This amoeba lives in the lumen of the colon and does not enter the tissues of the wall. It is a harmless species (non-pathogenic) feeding on bacteria, particles of undigested food and other debris but never on blood cells or other lining tissues of the host, therefore, considered as end commensal.The trophozoite measures 15 to 40 microns (average individuals 20 to 35 microns) in diameter. The cytoplasm is not well differentiated into ecto-and endoplasm. The endoplasm is granular and contains bacteria, fecal debris of various sizes in food vacuoles. Nucleus is 5 to 8 microns in diameter containing a comparatively larger nucleolus which is not placed in the centre. The cyst is spherical or often ovoid, highly refractile; 10 to 30 microns in diameter. Immature cyst contains 1, 2 or 4 nuclei, one or more large glycogen bodies and small number of filamentous chromatoid bodies with sharply pointed ends. Mature cyst contains 8 nuclei and a few or not chromatoid bodies.

Entamoebahartmanni

This species closely resembles the minuta form of E. histolytica. It also inhabits the colon, invades the intestinal tissues and causes amoebic dysentery; but is less harmful thanE. histolytica. The trophozoites measure 9 to 14 µm in diameter and the mature cysts are less than 10µm in diameter. The nucleus is more compact.

Mode of transmission

The amoebiasis disease is transmitted by the following modes

- Fecal-oral route.
- Contaminated water and food.
- Direct hand to mouth (cysts under finger nails).
- Vegetables irrigated with sewage polluted water.
- Agency of flies, cockroaches, rats etc.
- Sexual contact via oral-rectal route.

Clinical Features

Approximately ninety percent of Entamoeba infections are asymptomatic. Risk factors that are associated with increased disease severity and mortality include young age, pregnancy, malignancy, malnutrition, alcoholism, and corticosteroid use. The symptoms can range frommild diarrhea to severe dysentery, with abdominal pain and watery or bloody diarrhea with mucous. In most cases because of the deep ulcers, the patients experience appendicitis like sharp pain and Amoebic liver abscesses are the most common manifestation of extra intestinal amoebiasis. Chronic symptoms such as pleuropulmonary abscess, brain abscess, and necrotic lesions on the perianal skin and genitalia have also been observed. Other systemic manifestations of the disease are headache, nausea and anorexia. The disease is chronic and slowly subsides.

Diagnosis

Amoebiasis is diagnosed from patients medical and travel history. Various diagnostic tools exist for the diagnosis of E. histolytica including microscopy, for the identification of cyst in stool sample (Figure 17.3). The other tests include serology, antigen detection, molecular techniques, and colonoscopy with histological examination. Identification of cysts or trophozoites in stool cannot accurately identify the disease caused by E. histolytica, because it is morphologically indistinguishable from E. dispar and E. moshkovskii which are considered as non-pathological species. The identification of E. histolytica-specific nucleic acids by PCR is quick, accurate, and effective in diagnosing both intestinal and extra intestinal disease.

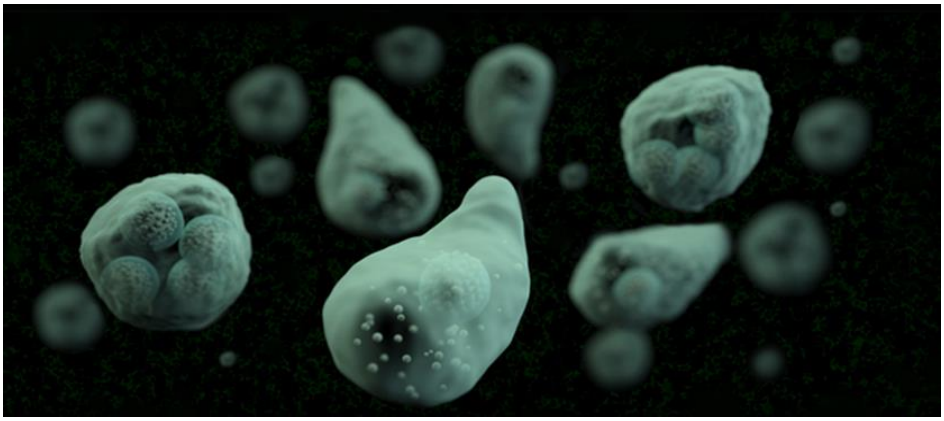

Figure-17.3: Microscopic structure of Entamoebahistolytica
(Courtesy by https://www.cdc.gov/parasites/amebiasis/index.html)

Therapy

Some asymptomatic infections are not treated; others may be treated with medications that work to eliminate the parasite from inside the intestines or other areas of the body. Metronidazole is the drug of choice for treating Entamoeba infections. The suggested course of drug is three times daily for 5 days in case of dysentery and a more prolonged course, for 10-14 days, in case of liver abscess or other extra-intestinal spread. Asymptomatic cyst passers should always be treated because they represent the most important reservoir of the parasite in the population. Carriers discharge 1.5 to 107 cysts daily. Amoeboquin (Diiodohydroxyquinoline) is the drug of choice for carriers. Surgical treatment infrequently may be required to remove large abscesses or if certain other complications such as gastrointestinal bleeding, perforation of the intestinal tract or toxic mega colon occurs.Vaccine is available for animals, and researchers are working on a vaccine for humans.

Control and Prevention

The disease is very difficult to eradicate because of substantial human reservoir of asymptomatic cases. Hence, proper sanitation and protected water supplies are essential for prevention of the disease. The cysts of the pathogen are destroyed by boiling water for at least 10 minutes, but chlorination does not destroy the cysts. It is possible to prevent amoebiasis by avoiding contaminated food and/or water. Vaccine is available for animals, and researchers are working on a vaccine for humans.

17.3 TRYPANOSOMA

The genus Trypanosoma belongs to Phylum -Euglenozoa**,** Class - Kinetoplastea, Order - TrypanosomatidaandFamily -Trypanosomatidae.

17.3.1Trypanosomabrucei

Humans are infected by two types, Trypanosomabruceigambiense (TbG) and Trypanosomabruceirhodesiense (TbR). T. brucei is a typical unicellular eukaryotic cell, and measures 8 to 50μm in length. It has an elongated body having a streamlined and tapered shape. Its cell membrane (called pellicle) encloses the cell organelles, including the nucleus, mitochondria, endoplasmic reticulum, Golgi apparatus, and ribosomes. In addition, there is an unusual organelle called the kinetoplast(Figure 17.4), which is made up of numerous circular DNA (mitochondrial DNA) and functions as a single large mitochondrion. The kinetoplast lies near the basal body with which it is indistinguishable under microscope. From the basal body arises a single flagellum that run towards the anterior end. Along the body surface, the flagellum is attached to the cell membrane forming an undulating membrane. Only the tip of the flagellum is free at the anterior end. The cell surface of the bloodstream form features a dense coat of variant surface glycoproteins (VSGs) which is replaced by an equally dense coat of procyclins when the parasite differentiates into the procylic in the tsetse fly midgut.
Trypanosomatids show several different classes of cellular organization of which two are adopted by Trypanosomabrucei at different stages of the life cycle:

Epimastigote: It is found in tsetse fly. Its kinetoplast and basal body lie anterior to the nucleus, with a long flagellum attached along the cell body. The flagellum starts from the center of the body.

Trypomastigote: It is found in mammalian hosts. The kinetoplast and basal body are posterior of nucleus. The flagellum arises from the posterior end of the body.

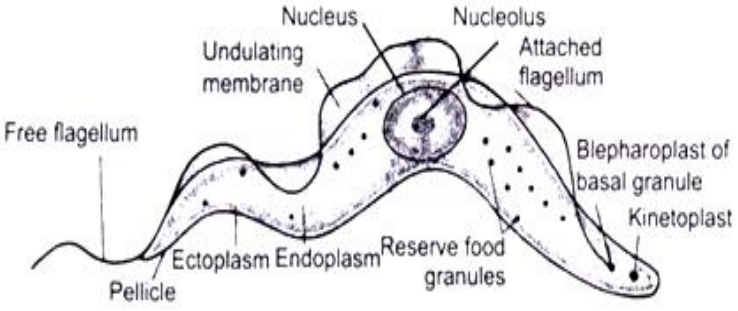

Figure-17.4:Trypanosoma

(Courtesy by https://www.proprofs.com/flashcards/story.php?title=epizoo-final_2)

Life Cycle

Trypanosomabrucei needs two hosts to live and reproduce. Its **life cycle** starts, when an infected tsetse fly bites human skin. Infection occurs when a vector tsetse fly bites a mammalian host (Figure 17.5).

Growth stages in Humans

The fly injects the metacyclictrypomastigotes into the skin tissue. The trypomastigotes enter the lymphatic system and into the bloodstream. The initial trypomastigotes are short and stumpy. Once inside the bloodstream, they grow into long and slender forms. Then, they multiply by binary fission. The daughter cells then become short and stumpy again. The long slender forms are able to penetrate the blood vessel endothelium and invade extravascular tissues, including the central nervous system (CNS). Sometimes, wild animals can be infected by the tsetse fly and they act as reservoirs. In these animals, they do not produce the disease, but the live parasite can be transmitted back to the normal hosts.

Growth stages in Tsetse fly

The short and stumpy trypomastigotes are taken up by tsetse fly during blood meal. The trypomastigotes enter the midgut of the fly where they become procyclictrypomastigotes. These rapidly divide to become epimastigotes. The epimastigotes migrate from the gut via the proventriculus to the salivary glands where they get attached to the salivary gland epithelium. In the salivary glands, some parasites detach and undergo transformation into short and stumpy trypomastigotes. These become the infective metacyclictrypomastigotes. They are injected into the mammalian host along with the saliva on biting. Complete development in the fly takes about 20 days.

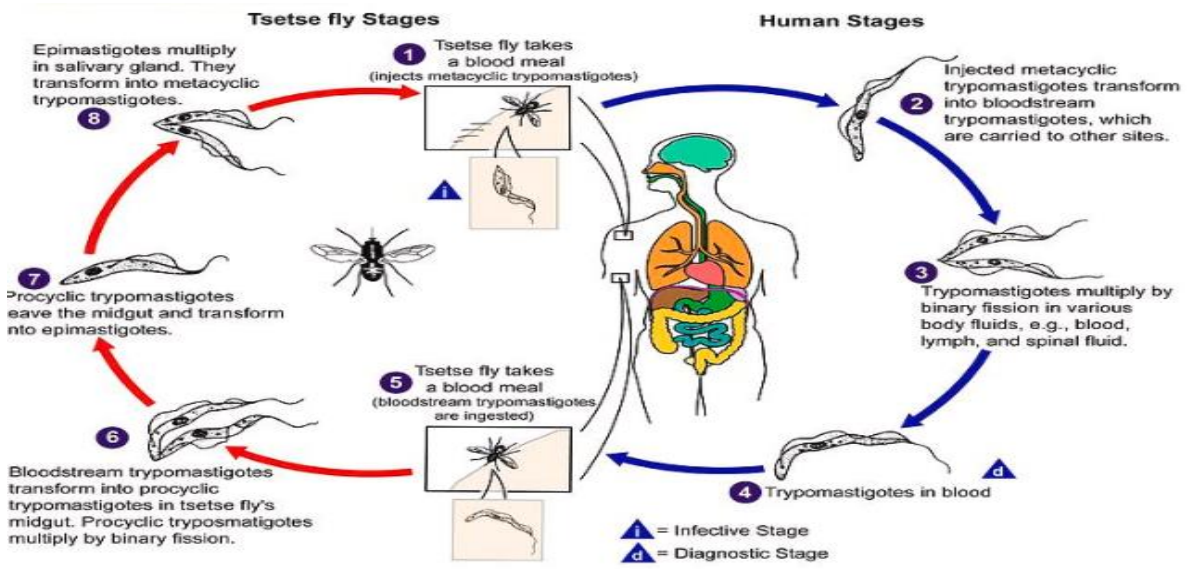

Figure-17.5:Life cycle of Trypanosomabrucei. Stages in Tsetse fly and Human.

(Courtesy by https://fineartamerica.com/featured/african-sleeping-sickness-life-cycle-cdcscience-photo-library.html)

Pathogenesis

Parasites injected into the host by the insect vector first cause an inflammatory reaction characterized by a localized tender reddish swelling (known as a chancre). Trypanosomes then multiply in the plasma and interstitial fluid causing acute to sub-acute febrile illness. A classic sign of T. b. gambiense infection is the enlargement of the cervical lymph glands at the back of the neck (known as winter bottom's sign). T. b. gambiense usually causes chronic disease with neurological involvement, meningoencephalitis, lethargy and coma (hence 'sleeping' sickness). Parasite development occurs in cyclic waves moderated by host immune responses. Trypanosomes have a glycoprotein coat on the outer surface of the cell membrane which is highly antigenic and leads to the production of host antibodies which acts together with complement, to lyse parasites. The repeated cycles of host antibody production and parasite destruction leads to cyclic fevers, macroglobulinemia, microvascular damage, coagulopathy, and perivascular inflammation. When parasites penetrate the blood-brain barrier they cause encephalitis, coma and death.

Other species of Trypanosoma

There are many species of Trypanosoma, which are hemoparasites that cause diseases in humans and animals. Some of the different species include:

Trypanosomacongolense
Causes nagana in cattle, horses, and camels. It is considered as the most pathogenic of the trypanosomes that affect livestock.

Trypanosomavivax
Causes nagana in animals, mainly in West Africa, but has spread to South America.

Trypanosomaequiperdum
Causes dourine, or covering sickness, in horses and other equids. It can be spread through sexual contact.

Trypanosomaevansi
Causes a form of surra in certain animals, including camels, horses, and buffaloes. It is spread by hematophagous flies, such as tabanids.

Trypanosomacruzi
Causes Chagas disease in humans.

Trypanosomatheileri

A large trypanosome that infects ruminants. It is transmitted by a variety of vectors, including tabanids and mosquitoes.

Clinical features

The incubation period varies from a few days to several weeks or months. A local infection may occur with a large 2 to 10cm red area or sore at the site where the fly originally bite. CNS signs can present a few months (T.b. rhodesiense) to several years (T.b. gambiense) after infection. Clinical signs include coma, confusion abnormal behavior, insomnia (sleeping trouble), and somnolence (extreme fatigue).

Diagnosis

Early diagnosis is difficult because signs and symptoms in the first stage are non-specific and because diagnostic measures are insensitive. Diagnosis requires confirming the presence of the parasite in any body fluid. Reliable serologic testing for T. b. rhodesiense is not available and microscopic detection of the parasite is definitive diagnosis. Serologic testing for T. b. gambiense is used for screening purposes only and the definitive diagnosis rests on microscopic observation of the parasite. Recently, rapid diagnostic tests for T. b.gambiense infection were developed and introduced to use in the field in endemic countries. Staging for both T. b. gambiense and T. b. rhodesiense (i.e., assessment of neurological infection) is performed by microscopic examination of CSF collected by lumbar puncture on a wet preparation looking for motile trypomastigotes and white blood cells (WBC).

Treatment

Treatment is based on symptoms and laboratory results. The drug choice depends on the infecting species and the stage of infection. Pentamidineisethionate and suramin are usually used for treating the hemolymphatic stage of West and East African Trypanosomiasis, respectively. Melarsoprol is used for late disease with central nervous system involvement (infections by T.b. gambiense or T. b. rhodiense).

Control and Prevention

Currently there are few medically related preventions options for African Trypanosomiasis (no vaccine exists for immunity). Although the risk of infection from a tsetse fly bite is minor (estimated at less than 0.1%), the use of insect repellants, wearing long-sleeved clothing, avoiding tsetse-dense areas, implementing bush clearance methods and wild game culling are the best options to avoid infection available for local residents of affected areas. Prevention involves avoiding being bitten by tsetse flies, but this can be difficult as they are persistent day time feeders and can bite through thin clothing. Control measures based on vector eradication (using insecticidal sprays, fly traps, or clearing vegetation).

17.4 SUMMARY

Entamoebahistolytica is an important parasite of humans, in whom it often produces severe amoebic dysentery, which may be fatal. Simple amoebae move almost continually using their pseudopodia refers to as amoeboid movement. Many have no definite shape, and their internal structures occupy no particular position. The single nucleus, contractile and phagocytic vacuoles, and ecto- and endoplasm shift as the amoeba move. Amoebae engulf a variety of materials through phagocytosis. Reproduction in the amoebae is by simple asexual binary fission, however some can form cysts.

The trypanosomes of Zooflagellates are the important blood pathogens of humans and animals in certain parts of the world. They are also called as hemoflagellates as they live in the blood. The trypanosomes cause the aggregate of diseases termed as trypanosomiasis. Trypanosome bruceigambiense, found in the rain forests of west and central Africa, and T. bruceirhodesiense found in the upland savannas of east Africa. For these two trypanosomes, the reservoirs are the domestic cattle and wild animals, within which the parasites cause severe malnutrition. Both these species use tsetse flies as intermediate hosts. They cause interstitial inflammation and necrosis within the lymph nodes and small blood vessels of the brain and heart. Trypanosomiasis is diagnosed by finding motile parasites in fresh blood and by serological testing.

17.5 TECHNICAL TERMS

Entamoeba, Trophozoite, Amoebiasis, Trypanosoma, Sleeping sickness, Tsetse fly

17.6SELF ASSESSMENT QUESTIONS

Q.1 Write short notes on morphology of Entamoebahistolytica.

Q.2 Write short notes on sleeping sickness.

Q.3 Give a detailed account on life cycle and pathogenesis of Trypanosoma.

Q.4 Give anaccount on transmission, pathogenesis and treatment of Entamoebahistolytica.

17.7 SUGGESTED READINGS

1. Microbiology– Prescott, et.al, 10th Edition, McGraw-Hill Education, 2017.
2. Medical Microbiology- JawetzMelnick&Adelbergs, 27th Edition, Jaypee medical publishers, 2016.
3. Medical Microbiology - Baron S, editor. 4th editionGalveston (TX): University of Texas Medical Branch at Galveston; 1996.
4. Microbiology - Michael Pelczar, McGraw Hill Education; 5thedition

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LESSON – 18

PROTOZOA GENERA - LEISHMANIA AND TRICHOMONAS

OBJECTIVE OF THE LESSON

Students will understand the morphological characters and pathogenesis of the protozoan genera viz., Leishmaniasps. andTrichomonassps.

STRUCTURE OF THE LESSON

18.1 INTRODUCTION

Leishmaniadonovani is the causative agent of visceral leishmaniasis, also known as Kala-azar, Black Fever, Dum-Dum fever, Asian fever, Assam fever, or infantile splenomegaly in various regions.The parasite is named after the scientists who discovered it—Leishman and Donovan, both of whom reported the parasite in 1903.Leishman first identified the parasite in the spleen smear of a soldier in England who died from a fever contracted at Dum-Dum, Kolkata.Donovan found the same parasite in the spleen of a patient with kala-azar in India.The sand fly (Phlebotomusargentipes) was identified as the vector by the Indian Kala-azar Commission (1931-1934).

Trichomoniasis is a very common sexually transmitted disease (STD). It is caused by Trichomonasvaginalis, a protozoan parasite. T.vaginalis is one of the commonest sexually transmitted pathogens in the world, with an estimated 170 million cases occurring each year. However, exact numbers are difficult to obtain because the infection is not nationally reportable and many infections are asymptomatic. It is more common in females than males. It is the most common non-viral STI in the U.S., with an estimated 3.7 million prevalent cases. The incidence of trichomoniasis in Europe is similar to that in the United States.

18.2 LEISHMANIA

The Leishmania genus of protozoa belongs the Phylum - Euglenozoa, Class – Kinetoplastea, and Order – Trypanosomatida.

18.2.1 Leishmaniadonovana

The parasitic protozoan, Leishmaniadonovanahas two forms namely Amastigote and Promastigote (Figure 18.1).

1. Amastigote

A flagellum-free stage of the parasite that is found inside macrophages, polymorphonuclear leukocytes, or endothelial cells in humans and other mammals.Amastigotes are small, round to oval, measuring 2-3 µm in length.Known as LD bodies (Leishman-Donovan bodies). The cell membrane is delicate, visible mainly in fresh specimens. The nucleus is oval or round, less than 1 µm in diameter and centrally located. A rod-shaped kinetoplast lies at a right angle to the nucleus, containing both DNA and mitochondrial structures.The axoneme (rhizoplast) extends from the kinetoplast and reaches the body margin.Vacuoles appear as clear, unstained areas adjacent to the axoneme.Giemsa or Wright stain shows a pale blue cytoplasm, a red nucleus, and a deep red kinetoplast.

2. Promastigote

Found in the sand fly gut and in culture media. Promastigotes are slender, spindle-shaped, measuring 15-25 µm in length and 1.5-3.5 µm in width.A single nucleus is centrally located and the kinetoplast is located near the anterior end. The single flagellum is delicate and measures 15-28 µm, often as long as or longer than the body. The flagellum does not curve around the body, so there is no undulating membrane. Leishman stain shows a blue cytoplasm, pink or violet nucleus, and a bright red kinetoplast.

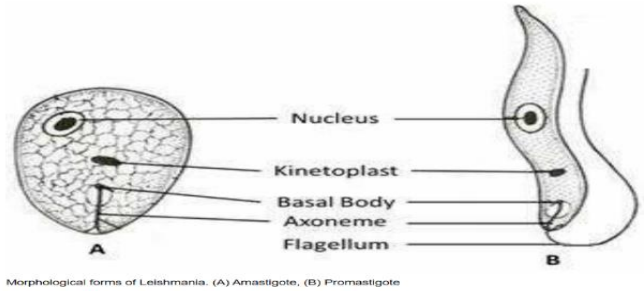

Figure-18.1: Morphological forms of Leishmania a) Amastigote b) Promastigote

(Courtesy by https://www.researchgate.net/figure/Morphological-forms-of-Leishmania-A-Amastigote-B-Promastigote_fig1_371566824)

Life Cycle

The life cycle of Leishmaniadonovani includes both amastigote and promastigote forms. The parasite is transmitted to humans and other vertebrates through the bite of an infected female

sand fly. During a blood meal, the sand fly deposits promastigotes onto the skin, which are then phagocytized by macrophages. Inside these cells, the promastigotes transform into amastigotes and multiply by binary fission in the reticuloendothelial system.As infected cells rupture, amastigotes are released, infecting new cells and continuing the cycle. Some amastigotes are taken up by sand flies during a subsequent blood meal.Inside the sand fly, the amastigotes transform into promastigotes, multiply, and migrate to the fly's pharynx and buccal cavity, completing the cycle when the fly bites a new host (Figure 18.2).

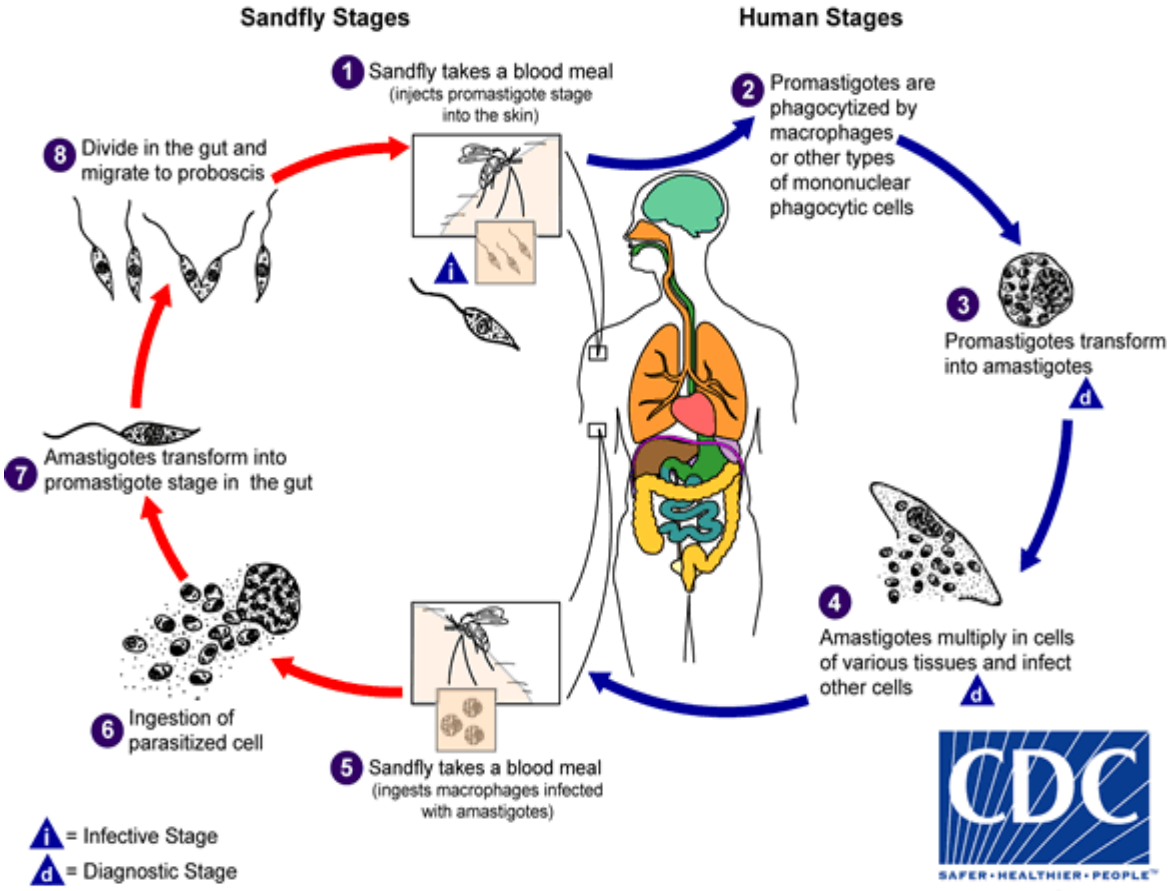

Figure-18.2: Life cycle of Leishmaniadonovani

(Courtesy by https://www.cdc.gov/dpdx/leishmaniasis/index.html)

Other species associated with leishmaniasis

- **L. donovani**complex: Includes L. donovani, L. infantum, and L. chagasi.
- **L.mexicana**complex: Includes L. mexicana, L. amazonensis, and L. venezuelensis.
- **L. tropica**: A species that typically causes dermatologic manifestations
- **L. major**: A species that causes leishmaniasis in the Mediterranean region, America, central Asia, and Middle East

- **L. aethiopica**: A species that causes leishmaniasis in the Mediterranean region, America, central Asia, and Middle East
- **L. braziliensis**: A species that causes leishmaniasis in South America
- **L. guyanensis**: A species that causes leishmaniasis in South America
- **L. panamensis**: A species that causes leishmaniasis in South America

Transmission

Leishmaniadonovani is primarily transmitted by the bite of infected female sand flies of the Phlebotomus and Lutzomyia genera.Less common transmission routes include: 1. Blood transfusions, 2. Congenital infection, 3. Accidental inoculation of cultured promastigotes in laboratory workers, and 4. Sexual intercourse. Males are more affected due to increased exposure through occupation or leisure activities.

Pathogenesis

Upon inoculation, promastigotes are deposited on the skin and bind to macrophages, where they are activated by biologically active substances from the sand fly.The parasite activates complement and binds to specific receptors on the macrophages, facilitating infection.The immune response plays a key role in the outcome of infection, with marked suppression of the cell-mediated immunity (CMI) to leishmanial antigens in severe cases.The infection primarily affects the reticuloendothelial system (RE), leading to enlarged spleen, liver, and bone marrow, with characteristic pathological changes including increased parasitized macrophages and hyperplasia of reticular cells.

Clinical Symptoms

Visceral leishmaniasis (VL): Kala-azar or black fever or dum-dum fever—the most severe form. The symptoms include - Fever and pyrexia, Splenomegaly and hepatomegaly (often with jaundice), Lymphadenopathy, Anemia, Leucopenia and thrombocytopenia, Skin lesions, and Hypergammaglobulinemia.

Post-Kala-azar Dermal Leishmaniasis (PKDL): A cutaneous manifestation that can develop after VL.

Laboratory Diagnosis

1. Specimens:
    - Splenic aspiration, bone marrow aspiration, lymph node aspiration, or peripheral blood.
2. Microscopy:
    - LD bodies can be identified in stained smears from bone marrow, liver, lymph nodes, or peripheral blood.
    - Giemsa or Wright stains are commonly used.

3. Culture:
    - Blood or tissue samples are cultured to observe promastigote forms.
4. Blood Count:
    - Blood tests show leucopenia, anemia, and thrombocytopenia.
5. Napier's Aldehyde Test:
    - Detects increased gamma globulin in the serum.
6. Serological Tests:
    - Direct Agglutination Test (DAT) and rk39-based Immunochromatographic Test (ICT) are commonly used for diagnosing VL.
    - Leishmanin or Montenegro Test is a delayed hypersensitivity test.

Treatment

Penta-valentantimonials (e.g., Meglumineantimonate, Sodium stibogluconate)interferes with the parasite's metabolism.Dosage: 20 mg of antimony per kg/day for at least 20-30 days.Other drugs include - pentamidine, amphotericin B, miltefosine, and interferon.

Prevention and Control

- Reservoir control: Treat infected individuals, especially those with PKDL.
- Vector control:
    - Reduce sand fly populations with insecticides like DDT, dieldrin, and malathion.
    - Use of insect repellent, bed nets, and window screens.
- Health education to the community about transmission routes and prevention strategies.

18.3 TRICHOMONAS

The genus Trychomonasbelongs to Phylum – Metamonada, Class – Trichomonadea, Order – Trichomonadida and Family –Trichomonadidae.

18.3.1 Trichomonasvaginalis

Trichomonasvaginalis varies in size and shape, with the average length of 10 μm and width of 7μm. It exists in only one morphological stage, a trophozoite, and cannot encyst. The T. vaginalistrophozoite is oval or pear shaped. Trichomonads have 4 flagella that project from the organism's anterior and 1 flagellum that extends backward across the middle of the organism, forming an undulating membrane (Figure 18.3). An axostyle, a rigid structure, extends from the organism's posterior end. The axostyle may be used for attachment to surfaces and may also cause the tissue damage seen in trichomoniasis infections.

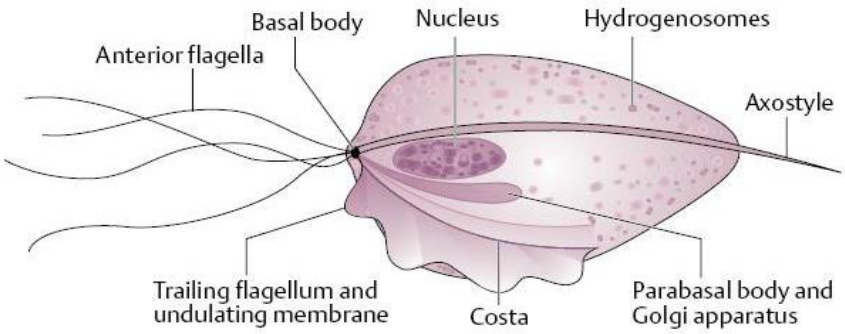

Figure-18.3: Morphology of Trichomonasvaginalis

(Courtesy by https://www.hakeem-sy.com/main/node/31747)

Life cycle

Life cycle of T. vaginalis is simple and is completed in a single host either male or female (Figure 18.4).The infection is transmitted sexually from a woman acting as a reservoir of infection to man.In the female, the parasite gets nourishment from the mucosal surface of the vagina and from the ingested bacteria and erythrocytes.On sexual contact, trophozoites are transmitted to male and localize in the urethra and prostate gland, where it replicates by longitudinal binary fission.It begins by division of the neuromotor apparatus and finally separation of cytoplasm into two daughter trophozoites. The trophozoites are the infective stages. These trophozoites probably undergo replication in the same way as seen in the vagina in females.

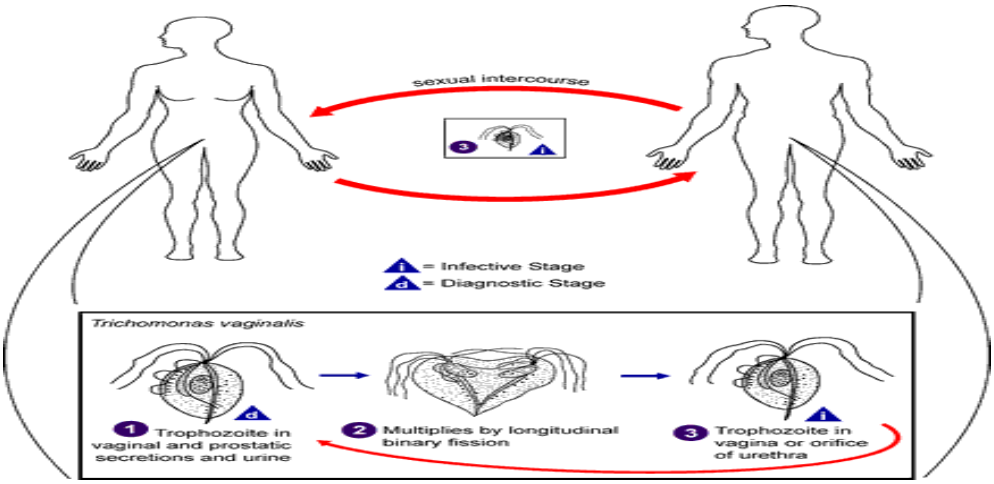

Figure-18.4: Life cycle of T. vaginalis

(Courtesy by https://web.stanford.edu/group/parasites/ParaSites2005/Trichomoniasis/lifecycle.htm)

Trichomonas species that infect humans

- Trichomonasvaginalis: The most common species that infects humans, and the cause of trichomoniasis. It's found in the lower female genital tract, male urethra, and prostate gland.
- Trichomonastenax: Found in the oral cavity of humans.
- Pentatrichomonashominis: Formerly called T. hominis, this species has five free, anterior flagella.

Trichomonas species that infect animals

- Trichomonasbrixi: Inhabits the oral cavity of dogs and cats.
- Trichomonasgallinae: Inhabits the upper digestive tract of birds, such as pigeons and doves.
- Trichomonasgypactinii: Inhabits the upper digestive tract of scavenging birds of prey, such as vultures.
- Trichomonasstableri: Inhabits the upper digestive tract of pigeons.
- T. foetus: Causes chronic diarrhea in domestic cats.

Clinical features

Trichomoniasis signs and symptoms for women include

- An often foul-smelling vaginal discharge — which might be white, gray, yellow or green.
- Genital redness, burning and itching.
- Pain with urination or sexual intercourse.

Trichomoniasis rarely causes symptoms in men which include:

- Irritation inside the penis.
- Burning with urination or after ejaculation.
- Discharge from the penis.

Diagnosis

Trichomoniasis symptoms are similar to those of other sexually transmitted infections (STIs). It can’t be diagnosed by symptoms alone. A number of tests can diagnose trichomoniasis, including:

- Cell cultures.
- Antigen tests (antibodies bind if the Trichomonas parasite is present, which causes a color change that indicates infection).
- Tests that look for Trichomonas DNA.
- Examining the samples of vaginal fluid (for women) or urethral discharge (for men) under a microscope.

Treatment

The most common treatment for trichomoniasis, even for pregnant women, is to swallow one mega dose of either metronidazole (Flagyl) or tinidazole (Tindamax). If untreated, trichomoniasis can last for months to years.

Prevention

To prevent the risk of infection and re infection the patients has to take care the following things like

- Not having sex with multiple partners.
- Avoiding sex for 7 to 10 days after treatment for trichomoniasis.
- Not using a douche, as this can affect the healthy bacteria in the vagina.
- Not abusing drugs and alcohol, as these increases the risk of unsafe sex.
- Using condoms correctly during sex.

18.4 SUMMARY

Leishmanias are flagellated protozoa that cause of group of human diseases collectively called as leishmaniasis. The primary reservoirs of these parasites are canines and rodents. All species of Leishmania use sand flies of the genus Phlebotomus as intermediate hosts. The leishmanias are transmitted from animals to humans or between humans by these sand flies. When an infected sand fly takes a human blood meal, it introducesthe flagellated promatigotes into the skin of the definitive host. Within the skin, the promatigotes are engulfed by macrophages, multiply by binary fission and from small non-motile cells called amastigotes. These destroy the host cell, and are engulfed by other macrophages in which they continue to develop and multiply.

Trichomoniasis (or “trich”) is a very common sexually transmitted disease (STD). It is caused by infection with a protozoan parasite called Trichomonasvaginalis. Infection is more common in women than in men. Older women are more likely than younger women to have been infected with trichomoniasis. In response to the parasite, the body accumulates leukocytes at the site of the infection. In females, this usually results in a profuse purulent vaginal discharge that is yellowish to light cream in colour and characterized by a disagreeable odour and also itching. Males are generally asymptomatic because of the trichomanacidal action of prostatic secretions, but at times burning sensation occurs during urination. In females, diagnosis is done by microscopic examination of the discharge and identification of the parasite. Infected males will demonstrate the parasite in semen or urine. Disease diagnosed by symptoms, include Itching, burning, redness or soreness of the genitals. Treatment consists of antibiotic administration with metronidazole and tinidazole.

18.5 TECHNICAL TERMS

Leishmaniasis, Trichomaniasis, Trophozoites, Kala-azar,amastigote, promastigote, Dum-dum fever, vaginal discharge.

18.6 SELF ASSESSMENT QUESTIONS

Q.1 Give a detailed account on transmission and life cycle of Leishmaniadonovani.
Q.2 Give a detailed account on transmission, pathogenesis and treatment ofTrichomoniasis caused by Trichomonasvaginalis.

18.7 SUGGESTED READINGS

1. Microbiology – Prescottet.al., 10th Edition, McGraw-Hill Education, 2017.

2. Medical Microbiology - JawetzMelnick&Adelbergs, 27th Edition, Jaypee medical publishers, 2016.

3. Medical Microbiology - Baron S, editor. 4th editionGalveston (TX): University of Texas Medical Branch at Galveston; 1996.

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LESSON – 19

PROTOZOA GENERA - GIARDIA, BALANTIDIUMAND PNEUMOCYSTIS

OBJECTIVE OF THE LESSON

Students will understand the characteristic features, pathogenesis, diagnosis and treatment of the infections caused by *Giardia*, *Balantidium* and *Pneumocystis*.

STRUCTURE OF THE LESSON

19.1 INTRODUCTION

*Giardia intestinalis*also called as *G. lamblia* and*G. duodenalis* is a parasitic protozoan that cause the Giardiasis disease. It was discovered by van Leeuwenhoek in 1681 when he examined his own stools. This species is worldwide in distribution, and it affects children more seriously than the adults. Transmission is most frequent by cyst-contaminated water supplies. Giardiasis disease varies in severity and asymptomatic carriers are common. The disease can be acute or chronic. The symptoms of acute giardiasis disease includes severe diarrhea, epigastric pain etc., whereas the intermittent diarrhea is the main symptom with chronic giardiasis. Laboratory diagnosis is based on the identification of trophozoites in case of severe diarrhea condition or cysts in stools.

Balantidium coli is a protozoan parasite responsible for the disease Balantidiasis.*B. coli* is found worldwide, but disease occurs most commonly in parts of the developing world including Latin America, Southeast Asia, Papua New Guinea and parts of the Middle East. Humans are usually resistant to infection; disease generally occurs in debilitated or poorly nourished patients. Pigs are the primary reservoirs for human infection and most cases occur in people in close proximity to pigs, although rats and other mammals also transmit disease.

Pneumocystis was first described in 1909 by Carlos Chagas. He initially misidentified it as a schizogonic form of *Trypanosomacruzi*, but, in 1912, husband and wife researchers Delanoë and Delanoë at the Institut Pasteur in Paris observed the organism in *Trypanosoma*-free rats and concluded that it was a new organism, proposing the name *Pneumocystis carinii*. The organism was initially classified as a protozoan, but there was ongoing controversy in the subsequent decades about whether to classify it as a protozoan or fungus. *Pneumocystis*

carinii is a cause of diffuse pneumonia in immunocompromised hosts. Even in fatal cases, the organism and the disease remain localized to the lung. The pneumonia rarely, if ever, occurs in healthy individuals. *P.carinii*, an extracellular protozoan, has been observed in three forms. Diagnosis requires identification of *P.carinii* in lung tissue, obtained by invasive techniques, or in lower airway fluids. Experimental studies have shown that the organism can be transmitted by inhalation.

19.2 GIARDIA

The genus *Giardia* of protozoa belongs to Phylum – Sarcomastigophora, Class – Zoomastigophora, Order –Diplomonadida, andFamily – Hexamitidae. The most important type species of the genus is *Giardia intestinalis*.

Epidemiology

Giardiasis is a major diarrheal disease found throughout the world. Infection is more common in children than in adults. Nearly 33% of people in developing countries have had giardiasis. In the United States, *Giardia* infection is the most common intestinal parasitic disease affecting humans.

Morphology

G.intestinalis has two morphological stages - the trophozoite and the cyst. The trophozoite is pear shaped, with a broad anterior and much attenuated posterior. It is 10-12µm long and 5-7µm wide, bilaterally symmetrical, and has two nuclei.It is the active feeding stage of parasite which is responsible for colonization in intestine.The *G.intestinalis* cyst is oval or ellipsoidal in shape and measures 8-12µm in length and 7-10µm in breadth.Cyst is surrounded by a thick cyst wall. Cytoplasm is granulated and is separated from the cyst wall by clear space.A cyst contains 4 nuclei.It is an infective stage of parasite.This species infects a wide range of mammals, including humans, pets, and livestock. It's considered a multispecies complex because of genetic differences and host specificity. The species is divided into assemblages, which are further divided into genotypes. Assemblages A and B infect humans, and some sub genotypes have zoonotic potential.

Life cycle and Pathogenesis

The life cycle (Figure 19.1)is composed of 2 stages: the trophozoite, which exists freely in the human small intestine; and the cyst, which is passed into the environment. No intermediate hosts are required.The *G. intestinalis cysts* are highly infectious, and as few as 10 cysts can cause an infection in an individual. Infection occurs by the ingestion of cysts in contaminated water, food, or by the fecal-oral route.In the small intestine, the cyst matures and releases 2 trophozoites by excystation. The trophozoites pass into the small bowel where they multiply by longitudinal binary fission, with a doubling time of 9-12 hours. As trophozoites pass into the large bowel, encystation occurs.Both cysts and trophozoites can be found in the feces.The cyst is the stage found most commonly in non-diarrheal feces and

trophozoites are found in the diarrheal stools.Cysts in the environment are then ready to infect another host.

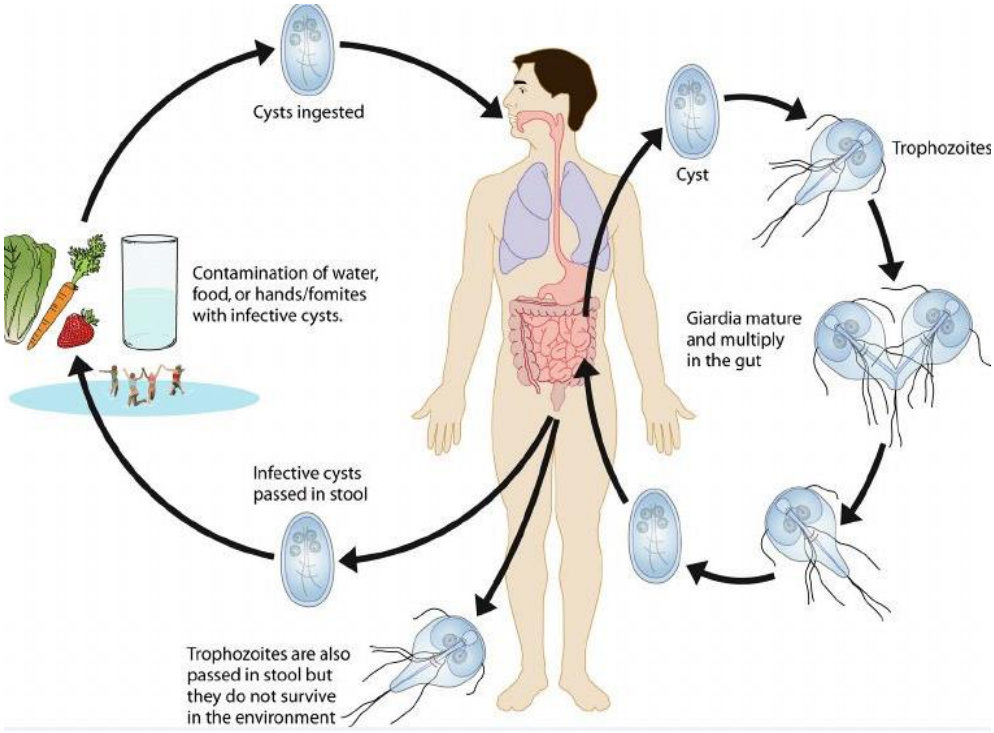

Figure-19.1: Life cycle of *G. intestinalis*

(Courtesy by https://www.researchgate.net/figure/Giardia-sp-life-cycle-Giardia-cysts-shed-in-the-feces-are-infectious-Infection-occurs_fig4_234087025)

Other *Giardia* species

- ***Giardia agilis***: Infects amphibians
- ***Giardia muris***: Infects mice and other mammals
- ***Giardia microti***: Infects voles and muskrats
- ***Giardia ardeae***: Infects birds
- ***Giardia psittaci***: Infects birds

Clinical features

- Diarrhea is the most common symptom of acute *Giardia* infection, occurring in 90% of symptomatic subjects. Abdominal cramping, bloating, and flatulence occur in 70-75% of symptomatic patients.
- Symptoms of chronic infection include chronic diarrhea, malaise, nausea, anorexia and weight loss.

Diagnosis

- The antigen test will identify more than 90% of people infected with *Giardia*. *Giardia* also can be diagnosed by examination of stool under the microscope for cysts or trophozoites.

- Other tests that can be used for diagnosing giardiasis are collection and examination of fluid from the duodenum or biopsy of the small intestine.

Treatment

- Several drugs can be used to treat *Giardia* infection. Effective treatments include metronidazole, tinidazole, and nitazoxanide.
- Alternatives to these medications include paromomycin, quinacrine, and furazolidone.

Control and Prevention

Eradication is most important because of substantial human reservoir of asymptomatic cases. Hence, proper sanitation and protected water supplies are essential for prevention of thedisease. The cysts of the pathogen are destroyed by boiling water for at least 10 minutes, but chlorination does not destroy the cysts.

19.3 *BALANTIDIUM*

The protozoan parasite,*Balantidium* belongs to Phylum – Ciliophora**,**Class – Litostomatea,Order – Vestibuliferida, and Family – Balantidiidae. *Balantidium coli*is the well-known ciliate protozoan that parasitize human beings.

Morphology

Balantidium coli is the only ciliate known to parasitize humans. It is the largest ciliated protozoan parasite of humans found in the large intestine of humans and other mammals. Most commonly found in tropical and subtropical regions.Most people infected with *Balantidium coli* experience no symptoms. People with compromised immune systems are more likely to experience severe symptoms. Ciliates represent a phylum of protozoa characterized, in at least one stage of development, by simple or compound ciliary organelles on the surface of their membranes that are used for locomotion. Ciliateshave 2 nuclei (one macronucleus and one micronucleus) and reproduce by transverse binary fission, conjugation, autogamy, and cytogamy.*B. coli* has 2 contractile vacuoles. Although contractile vacuoles are common to ciliates, they are rare in parasitic protozoa, which suggest that *B. coli* has a unique osmoregulatory capacity.*B. coli* has 2 developmental stages: a Trophozoite stage and a Cyst stage.

Trophozoite stage: Trophozoites can measure between 50-130 µm long by 20-70 µm wide.In trophozoites, the two nuclei are clearly visible. The macronucleus is long and kidney-shaped, and the spherical micronucleus is nestled next to it.Other distinguishing traits of the trophozoite include the opening, known as the peristome, at the pointed anterior end, which leads to the cytostome, or cell mouth. *Balantidium coli* reproduce during the trophozoite stage either by asexual transverse binary fission or sexual conjugation.

Cyst: The cyst is the infective stage of the *B. coli* life cycle. Encystation is the process of forming the cyst; this event takes place in the rectum of the host as feces are dehydrated or soon after the feces have been excreted. Excystation produces a trophozoite from the cyst

stage, and it takes place in the large intestine of the host after the cyst has been ingested.Cysts are smaller than trophozoites, measuring 40-60 µm across. Cysts are round and have a tough, heavy cyst wall made of one or two layers. Usually only the macronucleus and perhaps cilia and contractile vacuoles are visible in the cyst.

Life cycle or Pathogenesis

The cyst is the infective stage of *Balantium coli* life cycle (Figure 19.2). Once the cyst is ingested via feces-contaminated food or water, it passes through the host digestive system. The tough cyst wall allows the cyst to resist degradation in the acidic environment of the stomach and the basic environment of the small intestine until it reaches the large intestine. There, excystation takes place. Excystation produces a trophozoite from the cyst stage.

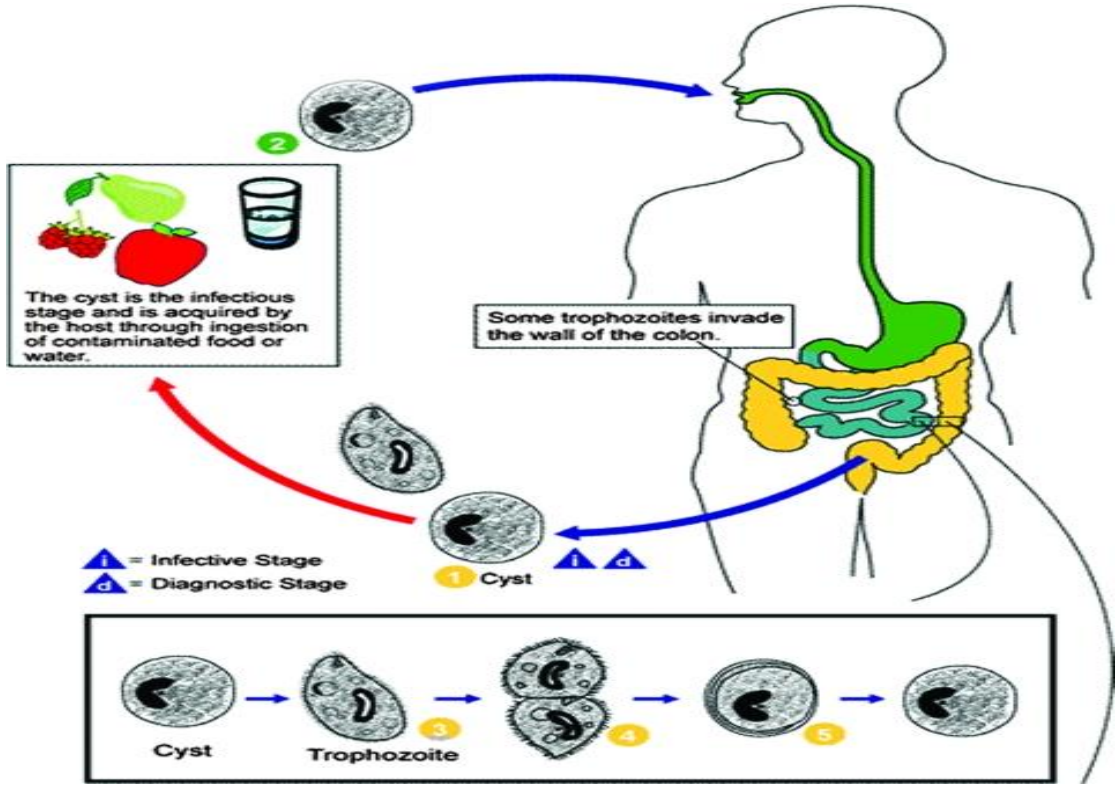

Figure-19.2:Life cycle of *Balantidium coli*

(Courtesy by http://www.antimicrobe.org/Lifecycle/b41lc.asp)

Then the motile trophozoite resides in the lumen of the large intestine, feeding on intestinal bacterial flora and intestinal nutrients. Trophozoites multiply by asexual binary fission or sexual conjugation (with the exchange of nuclear material). The trophozoite may become invasive and penetrate the mucosa of the large intestine Trophozoites are released with the feces, and encyst to form new cysts. Encystation takes place in the rectum of the host as

feces are dehydrated or soon after the feces have been excreted.Cysts in the environment are then ready to infect another host.

Other species of *Balantidium*

Balantidiumcaviae,Balantidiumsaigonensis, Balantidiumserpentina, Balantidium simile, Balantidiumsinensis, Balantidiumspinibarbichthys, Balantidiumsteinae, Balantidiumstrelkovi, Balantidiumstruthionis, Balantidiumsuis, and Balantidiumtapiri.

Clinical features

Most infections are asymptomatic.Symptomatic patients generally suffer similar to amebiasis, with diarrhea, dysentery, abdominal pain and weight loss.Chronic disease is most common, although fulminant colitis may occur, including perforation leading to peritonitis.Disease in the lung, urinary bladder and bone has been described.*B. coli* causes flask shaped ulcers in the large intestine, most commonly in the cecum and rectosigmoid.

Diagnosis

Diagnosis is usually made by the identification of mobile trophozoites in fresh stool or scraped from an ulcer seen during endoscopy.Rarely the diagnosis is made by examination of urine or bronchoalveolar lavage fluid, or by identification in biopsy or resection specimens

Treatment

Tetracycline is the drug of choice. Alternative treatments include metronidazole, ampicillin, iodoquinol and nitazoxanide. Immunosuppressed patients require longer treatment.

Control and Prevention

Eradication is most important to control the disease because of substantial human reservoir of asymptomatic cases. Hence, proper sanitation and protected water supplies are essential for prevention of the disease. The cysts of the pathogen are destroyed by boiling water for at least 10 minutes, but chlorination does not destroy the cysts.

19.4 *PNEUMOCYSTIS*

Morphology

The structural forms of *Pneumocystis carinii* that have been recognized are the cysts, which are thick-walled; the sporozoite, an intracystic structure; and the thin-walled trophozoite. The cyst is a spherical to ovoid structure 4 to 6 μm in diameter. It contains up to eight pleomorphic sporozoites. The trophozoite is a thin-walled extra cystic cell representing an excystedsporozoite. The organism does not enter the host cell, but instead attaches to its surface during a phase in the replicative cycle.

Life cycle and pathogenesis

The life cycle of *Pneumocystis jirovecii* involves two main phases: the asexual phase and the sexual phase.In the asexual phase, *Pneumocystis* replicates through mitosis, which consists of five stages. During prophase, the chromosomes replicate and condense. In prometaphase, the nuclear membrane and nucleolus break down, while fibers organize into the mitotic spindle. The chromosomes align along the spindle in metaphase, where molecular machinery checks that they are properly aligned for division. In anaphase, the spindle pulls the chromosomes apart, and in telophase, the chromosomes and spindles move to opposite sides of the cell, forming new nuclear membranes around each set. Cytokinesis then splits the cytoplasm, resulting in two daughter cells. After mitosis, the cell enters interphase, the phase where it ceases dividing.

The sexual phase begins when two haploid trophozoites conjugate, forming a round, thin-walled, mononuclear, and diploid early sporocyte. Within the early sporocyte, meiosis occurs, followed by mitotic division, resulting in a late sporocyte containing eight nuclei. The spores formed during this phase consist of a single nucleus surrounded by dense cytoplasm and include structures like a well-defined electron-dense mitochondrion, a developed rough endoplasmic reticulum, and many ribosomes. The spores can take various shapes, such as spherical or elongated. Once mature, they exit the cyst, likely through a foramen-like structure, and give rise to eight free haploid trophic forms. This life cycle contributes to the organism's ability to cause disease, particularly in immunocompromised individuals.The pathogenesis of *Pneumocystis jirovecii* begins when inhaled cysts reach the alveoli and release trophic forms, which adhere to and infect the alveolar epithelial cells. In immunocompetent individuals, the immune system controls the infection, but in immunocompromised hosts (e.g., HIV/AIDS, cancer, organ transplants), the immune response is insufficient, allowing the organism to proliferate. This leads to inflammation, alveolar damage, and impaired gas exchange, causing symptoms like fever, cough, and difficulty breathing.

Transmission

Pneumocystis jirovecii pneumonia (PCP) spreads from person to person through the air. Some healthy adults can carry the *Pneumocystis* sps. in their lungs without having symptoms, and it can spread to other people, including those with weakened immune systems. Incubation period range from 3 – 12 weeks.

Clinical features

The clinical features of *Pneumocystis jirovecii* pneumonia (PCP) primarily manifest as respiratory symptoms, particularly in immunocompromised individuals. Patients commonly present with fever, which is often low-grade but can become more pronounced. A dry, non-productive cough is typical, though it may become productive in more advanced stages of the infection. Shortness of breath, ranging from mild to severe, usually worsens with activity, and chest pain can occur due to inflammation of the lung tissue. Fatigue and generalized malaise are frequent complaints, and hypoxia, or low oxygen levels in the blood, can develop, leading to difficulty breathing and cyanosis in severe cases. Tachypnea or rapid breathing is also common due to impaired gas exchange. If left untreated, PCP can progress to respiratory

failure, potentially resulting in complications such as pneumothorax, and can be fatal, especially in individuals with significant immune suppression. Symptoms often develop gradually over several days to weeks.

Diagnosis

Diagnosis of *Pneumocystis jirovecii* pneumonia (PCP) typically involves a combination of clinical assessment, radiologic imaging, and laboratory tests.

1. Clinical suspicion: PCP should be suspected in immunocompromised individuals (e.g., those with HIV/AIDS, undergoing chemotherapy, or on long-term corticosteroid therapy) who present with characteristic symptoms such as cough, fever, dyspnea, and hypoxia.
2. Chest X-ray or CT scan: A chest X-ray typically shows diffuse bilateral infiltrates or a "ground-glass" appearance, which is suggestive of PCP. A high-resolution CT scan may provide more detailed images, revealing a more characteristic pattern of alveolar damage.
3. Laboratory tests:
    - Sputum or bronchoalveolar lavage (BAL): The most common diagnostic method involves collecting sputum or performing a bronchoscopy with BAL to obtain lung fluid. The presence of *Pneumocystis* cysts or trophic forms in these samples can confirm the diagnosis, typically using special staining techniques like Gomorimethenamine silver stain or immunofluorescence.
    - PCR (Polymerase Chain Reaction): PCR testing is highly sensitive for detecting *Pneumocystis jirovecii* DNA in respiratory samples, providing a more rapid and accurate diagnosis.
    - Beta-D-glucan assay: This test detects the presence of fungal cell wall components and can be elevated in PCP, though it is not specific for *Pneumocystis*.
4. Arterial blood gas (ABG): This may show hypoxia, which is common in PCP due to impaired gas exchange in the lungs.

Treatment

The treatment of *Pneumocystis jirovecii* pneumonia (PCP) typically involves trimethoprim-sulfamethoxazole (TMP-SMX) as the first-line therapy, administered orally for mild cases or intravenously for severe cases, over a 21-day course. Alternatives for those allergic to TMP-SMX include pentamidine, atovaquone, or clindamycin plus primaquine. Corticosteroids like prednisone are used in moderate to severe cases to reduce inflammation and improve respiratory function, especially if hypoxia is present. Prophylaxis with TMP-SMX or other agents is recommended for immunocompromised individuals to prevent PCP. Early treatment is crucial, as untreated PCP can be fatal.

Prevention and control

There is no vaccine to prevent PCP. A healthcare provider might prescribe medicine to prevent PCP for people who are more likely to develop the disease. The medicine most

commonly used to prevent PCP is called trimethoprim/sulfamethoxazole (TMP/SMX), which is also known as co-trimoxazole. Medicine to prevent PCP is recommended for some people infected with HIV, stem cell transplant patients, and some solid organ transplant patients.Healthcare providers might also prescribe medicine to prevent PCP in other patients, such as people who are taking long-term, high-dose corticosteroids.

19.4 SUMMARY

Giardiasis is a common parasitic infection caused by the protozoan *Giardia intestinalis*. Transmission usually occurs via the fecal-oral route (e.g., from contaminated drinking water) when traveling or living in an endemic region. *Giardia* live in two states: as active trophozoites in the human body and as infectious cysts surviving in various environments. Following the ingestion of the cyst, individuals may experience abdominal cramps and frothy, greasy diarrhea. Diagnosis of giardiasis involves analyzing stool for microscopic confirmation of cysts or trophozoites, and possibly immunoassays to detect antigens. Treatment consists of antibiotic administration with metronidazole.

Balantidiasis is a food borne illness that is caused by *Balantidium coli*, which is a microscopic protozoan found in feces. People contract balantidiasis by eating food or drinking water that has been contaminated by feces that contain this microorganism. Additionally, people who handle or live near pigs are at an increased risk for contracting this illness. When travelling through human body it releasesastrophozoites and as infectious cyst in outer environment. When it infects individuals may experience amoebiais with diarrhea. Diagnosis of giardiasis involves analyzing stool for microscopic confirmation of cysts or trophozoites, and possibly immunoassays to detect antigens. Treatment consists of antibiotic administration with metronidazole.

The taxonomy of *Pneumocystis* is uncertain and was in debate for some time. Initially, *Pneumocystis* species were classified as protozoan parasites, but basing on RNA sequencing and some other features now it is considered to be a yeast-like fungus.*Pneumocystis* is a saprophyte of low virulence with a worldwide distribution. Its primary habitat is the mammalian lung, where it causes opportunistic pneumonia. *Pneumocystis pneumonia* has been reported in dogs, pigs, horses, goats, primates, and humans. Subclinical or latent infections are common in rats, mice, guinea pigs, rabbits, cats, sheep and various wildlife species. The organism is found in 3 distinct morphologic stages: 1) The trophozoite (trophic form), in which it often exists in clusters, 2) The sporozoite (precystic form), and 3) The cyst, which contains several intracystic bodies (spores). PCP can develop in people with weakened immune systems due to cancer, HIV, autoimmune diseases, organ or bone marrow transplanted people and also long term users of corticosteroids or other immunosuppressive drugs.

19.5 TECHNICAL TERMS

Giardiasis, Balantidiasis, *Giardia*, *Balantidium*, *Pneumocyctis*, Trophozoites, Excystation, Cyst.

19.6SELF ASSESSMENT QUESTIONS:

Q.1 Give a detailed account on transmission, life cycle and treatment of Giardiasis.
Q.2 Give a detailed account on transmission, pathogenesis and treatment of Balantidiasis.
Q.3 Give a detailed account on *Pneumocystis*.

19.7SUGGESTED READINGS

Microbiology– Prescott, et.al, 10th Edition, McGraw-Hill Education, 2017.

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