GEBO-01

PLANT SCIENCE

DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY, HALDWANI

GEBO-01

PLANT SCIENCE

DEPARTMENT OF BOTANY

SCHOOL OF SCIENCES UTTARAKHAND OPEN UNIVERSITY

Phone No. 05946-261122, 261123
Toll free No. 18001804025
Fax No. 05946-264232, E. mail info@uou.ac.in
htpp://uou.ac.in

Expert Committee

Board of Studies

Programme Coordinator

Dr. S.N. Ojha
Assistant Professor
Department of Botany, School of Sciences
Uttarakhand Open University, Haldwani (Nainital) Uttarakhand

Unit Compiled from

S.No.	Name of the Unit	Units compiled from
1.	Microbes, Fungi andLichens	Unit 1,3,5 of BSCBO-101 https://www.uou.ac.in/sites/default/files/slm/BSCBO-101.pdf
2.	Phycology and Bryology	Unit 1,4,9 of BSCBO-102 https://www.uou.ac.in/sites/default/files/slm/BSCBO-102.pdf
3.	Pteridology and Gymnosperms	Unit 1,5 of BSCBO-103 https://www.uou.ac.in/sites/default/files/slm/BSCBO-103.pdf
4.	Introduction to Angiosperm Taxonomy	Unit 1,2,3,4 of BSCBO-201 https://www.uou.ac.in/sites/default/files/slm/BSCBO-201.pdf
5.	Plant Anatomy and Embryology	Unit 2,6,7 of BSCBO-202 https://www.uou.ac.in/sites/default/files/slm/BSCBO-202.pdf
6.	Plant Ecology	Unit 1,2,5 of BSCBO-203 https://www.uou.ac.in/sites/default/files/slm/BSCBO-203.pdf
7.	Plant Physiology and Biochemistry	Unit 5,6,7,9,10 & 11 of BSCBO-303 https://www.uou.ac.in/sites/default/files/slm/BSCBO-303.pdf
8.	Genetics and PlantBreeding	Unit 5,6,9 of BSCBO-302 https://www.uou.ac.in/sites/default/files/slm/BSCBO-302.pdf
9.	Cytology and Molecular Biology	Unit 1,2,4,5,6,7,8,12 of BSCBO-301 https://www.uou.ac.in/sites/default/files/slm/BSCBO-301.pdf
10.	Biodiversity Conservation	Unit 9,10,11,12 of BSCBO-201; Unit-9 of MSCBOT-603 https://www.uou.ac.in/sites/default/files/slm/BSCBO-201.pdf https://www.uou.ac.in/sites/default/files/slm/MSCBOT- 603.pdf

Unit Compiled by

Unit 1-5 compiled by Dr. Pushpesh Joshi, Department of Botany, UOU
Unit 6-10 compiled by Dr. Prabha Bisht Dhondiyal, Department of Botany, UOU

SLM formatted by

Dr. Pushpesh Joshi, Department of Botany, UOU
Dr. Prabha Bisht Dhondiyal, Department of Botany, UOU
Dr. Kirtika Padalia, Department of Botany, UOU

Title	**:**	**Plant Science**
ISBN No.	**:**	
Copyright	**:**	**Uttarakhand Open University**
Edition	**:**	**2023**

Published By: Uttarakhand Open University, Haldwani, Nainital-263139

CONTENTS

UNIT 1- MICROBES, FUNGI AND LICHENS

Contents:

1.1 OBJECTIVES

Microbiology is the study of organisms invisible to our naked eye. This branch of science explains the structure, nature, distribution, classification, occurrence, physiology pathogenicity and application of microbes. This unit deals with the introduction, general accounts, distribution, and classification of microbes and also about the soil, water and food microbiology.

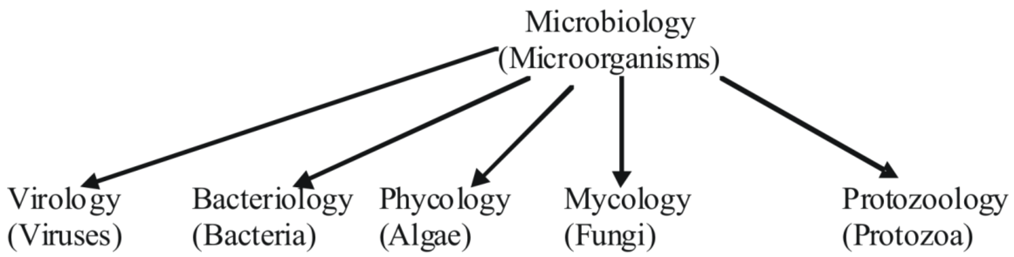
After reading this unit one is able to:

- Know about micro-organisms including fungi and lichens
- Learn the variety of microorganisms which occur in the environment surrounding us.
- Understand the existence of minute organisms and realize that these microscopic organisms are living and perpetuate themselves by reproduction.
- Discuss the distinct group of microbes which differ in form and other characters but resemble with each other in their small size and simple structure.
- Study the systematic position, and distribution of micro organisms.

1.2 INTRODUCTION

Microbiology is the study of organisms too small to be clearly seen by the unaided eye. Since objects less than about one millimeter in diameter cannot be clearly seen and must be examined with a microscope, such living objects are collectively referred as microorganisms or microbes. Therefore microbiology is defined as the study of microorganisms. A variety of organisms like bacteria, protozoa, viruses, fungi and algae are included in this category.

Regarding the place of microorganisms in the living organisms, satisfactory criteria were unavailable until late 1940, when more definite observation of internal cell structure was made possible with the aid of the powerful magnification provided by electron microscope. Two cell types were discovered among these microorganisms. In some organisms the cells



contains nuclear substance which was not enclosed by a nuclear membrane, while in others, a well-defined nucleus with a nuclear membrane was present. These two patterns were called prokaryotic and eukaryotic respectively. According to these special features of microorganisms, bacteria are prokaryotic and fungi, algae and protozoa are eukaryotic. Viruses are left out of these criteria as they are acellular organisms. Thus microbiology includes five major branches namely, virology, bacteriology, phycology, mycology, and protozoology.

1.3 GENERAL ACCOUNT OF MICROORGANISMS

Antony–van Leeuwenhoek (1632-1723) was the first who studied in detail the microbial content of a variety of natural substances under the microscope. The various natural substances studied by Leeuwenhoek were water from rain barrels, rivers, wells, sea, teeth scrapings and naturally fermented material like vinegar. His observations were confirmed by others, but only in nineteenth century, the extent and nature of microbial forms became more apparent.

- Microbes are unicellular or multicellular or non- cellular forms. Protozoa, bacteria and some algae and fungi are unicellular forms and are made up of single cells. While most of the algae and fungi are multicellular forms. Viruses lack a cellular structure and hence they are non-cellular particles and occupy a border line between living and non-living things.
- Based upon the presence or absence of nuclear membrane, microbes are of two types namely Prokaryotes and Eukaryotes. Prokaryotes have incipient nucleus which is suspended in the cytoplasm. This includes bacteria.
- The microbes such as protozoa, algae and fungi are eukaryote which contain a nucleus, with a nuclear membrane and is well separated from the cytoplasm.

1.3.1 General characteristics of Bacteria

1) Bacteria are small microscopic and least differentiated microorganisms. These are believed to be amongst the first primitive organisms on the earth possessing typical prokaryotic cell organization.
2) They are omnipresent, i.e. found in all possible habitats.
3) They are unicellular and may live in association with others in colonies.
4) The size, shape and arrangement of bacterial cells vary and their size is about .5 micron to 3 micron.
5) They exhibit a variety of shapes e.g., spheres (coccus), rods (bacillus), spirals (spirillum), curved (vibrio) etc (Fig.1.1).

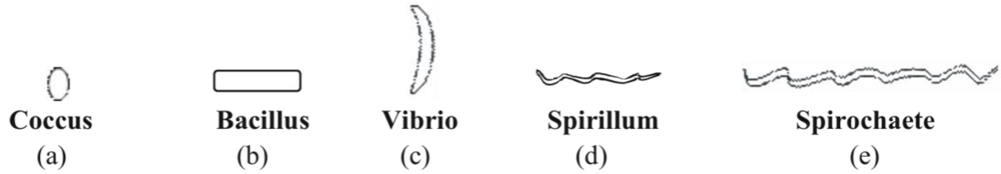


Fig.1.1. Different shapes of bacteria

6) They possess very rigid cell wall, which is not made up of cellulose, characteristic of plant cell walls. It generally contains a peptidoglycan (murein), lipid and lipopolysaccharides. The rigid cell wall determines the shape of bacterial cells.
7) Nuclear material is not enclosed in a nuclear membrane. Nucleolus is absent.
8) An extra chromosomal DNA called plasmid is usually present in the cytoplasm.

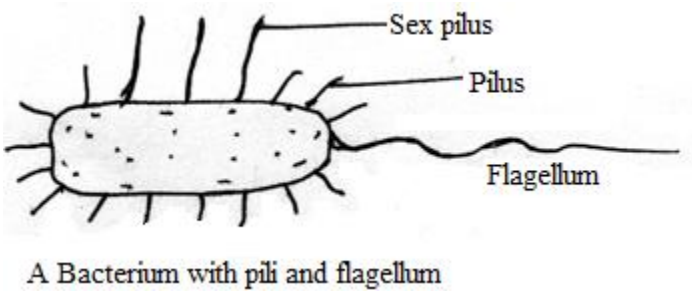


Fig.1.2. A bacterium showing appendages

9) Cell organelles includes 70s type ribosome and mesosome formed by invagination of plasma membrane.Otherorganelles such as mitochondria, lysosomes, Golgi body, endoplasmic reticulum,centriole etc. are absent.

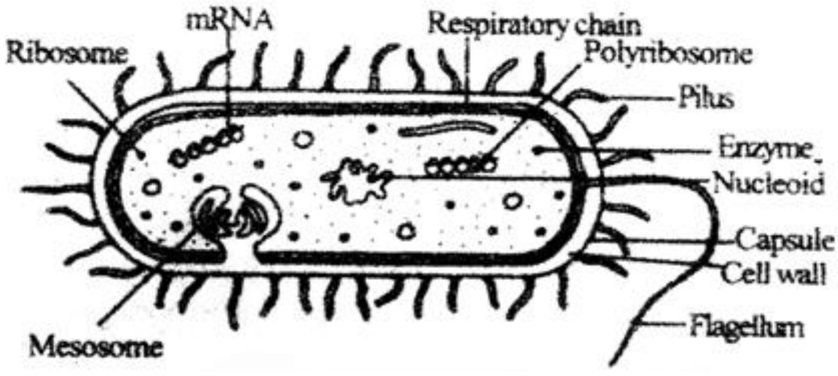


Fig.1.3.Structure of a typical bacterium (*E. coli*)

10) Appendages like flagella and pili are present. Some pili are longer in some bacteria and are called as sex pili (**Fig.1.2, 1.3**).

Motility is brought about by flagella. The Bacilli and spirilla are motile and the cocci are non-motile. Thus the bacteria may motile or non-motile.

11) When flagella are absent, the bacterium is called atrichous. In motile bacteria, the number and position of flagella vary. The arrangement may be monotrichous (a single polar flagellum), lophotrichous (a cluster of polar flagella), amphitrichous (Flagella at both the ends either singly or in cluster), cephalotrichous (two or more flagella at one end of the cell), peritrichous (cell surface evenly surrounded by several flagella) (**Fig.1.4)**.
12) The flagella are hair like or helical, consists of a single minute filament which is made up of fibrils of flagellin protein. Unlike hair a flagellum grows at its tip rather than at base.
13) Bacteria are either Gram positive or Gram Negative. Gram positive bacteria retain violet colour on Gram staining while Gram negative bacteria appear in red colour. This is because of the difference in their cell walls. The cell wall of gram positive bacteria contains several layers of peptidoglycan in addition to techoic acid and low quantity of lipoprotein and lipid. In gram negative bacteria, cell wall has thin layer of peptidoglycan and high amount of lipo protein and lipid. Techoic acid is absent in these bacteria.
14) In some bacteria, shorter and thinner hair like appendages are present on the surface of the cell wall. These structures are called pili or fimbrae. There function is to adhere to the cell surfaces and sometimes help in transfer of genome to other bacterial cells. These are called sex-pili.

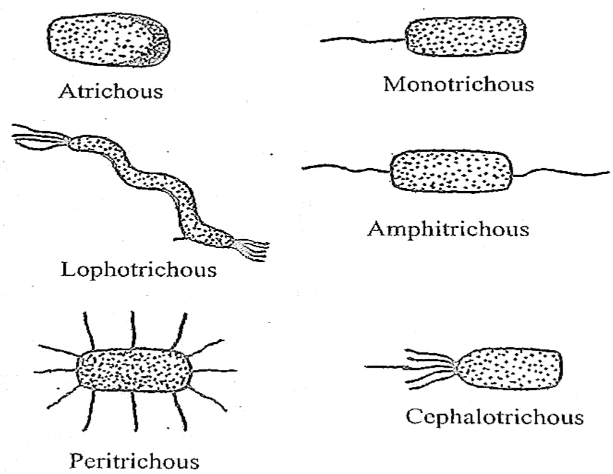


Fig.1.4. Showing flagellation in bacteria

15) A bacterial cell is protected by a cell envelope made up of a capsule, a cell wall and a plasma membrane. The bacteria covered by a capsule are called capsulated bacteria. While the bacteria which do not contain a capsule are called non- capsulated bacteria.

16) Bacteria may be heterotrophic or autotrophic, Heterotrophic may be parasitic, saprophytic or symbiotic. For nutrition, autotrophs use CO_2 as the source of carbon while heterotrophs use organic substances as the source of carbon.
17) Based on temperature tolerance of bacteria they are of three types:-
    - **Mesophilic** bacteria grow well in temperature between 25^0C -40^0C.
    - **Thermophilic** bacteria grow well above 40^0C.
    - **Psychrophilic** bacteria grow well in temperature less than 25^0C.
18) On the basis of availability of O_2 bacteria may be aerobic or anaerobic or facultative anaerobic.
    - Aerobic bacteria use oxygen for respiration.
    - Anaerobic bacteria use CO_2.
    - Facultative anaerobes use oxygen when it is available and use CO_2 when oxygen is not available.
19) Bacteria reproduce by binary fission, budding, fragmentation, endospores, exospores and conidiospores.
20) True sexual reproduction is lacking. However, genetic recombination occurs by conjugation, transformation and transduction.

1.3.2 Economic importance of Bacteria

Bacteria play important roles in different fields such as agriculture, industry etc. Some of them are mentioned below:

1.3.2.1 Role in agriculture

a) **Scavenging Role**: Saprophytic bacteria obtain food from organic remains such as animal excreta, fallen leaves, meat etc. They decompose these substances by action of digestive enzymes aerobically or anaerobically (known as fermentation). Thus they help in sanitation of nature, therefore also known as scavengers. e.g. *Pseudomonas*

b) **Nitrification:** *Rhizobium* bacteria, living in root nodules of leguminous plant symbiotically, helps in fixing atmospheric nitrogen. Similarly, *Nitrosomanas* and *Nitrococcus* convert ammonium salt to nitrites. Nitrites are further changed to nitrates by *Nitrobacter* and *Nitrocystis.* It enables plants to uptake nitrogen.

c) **Production of Organic Manure:** As stated above, saprophytic bacteria help in breaking of complex organic substance to simpler forms. Thus, in this process, they help to convert farm refuse, dung and other wastes to manure.

d) **Preparation of Ensilage:** Ensilage is preserved cattle fodder prepared by packing fresh chopped fodder sprinkled with molasses. Fermentation activity of bacteria produces lactic acid that acts as preservative in ensilage.

e) **Production of fuel:** Bacteria, while converting animal dung and other organic wastes to manure, help in production of fuel. Gober gas plant is an example of this process.

f) **Disposal of sewage:** Bacteria help in disposal of sewage by decomposing it and thus, help in environmental sanitation.

1.3.2.2 Role in industry

a) **Dairy Industry:** Bacteria such as *Streptococcus lactis* convert milk sugar lactose into lactic acid that coagulates casein (milk protein). Then, milk is converted into curd, yoghurt, cheese etc needed for the industry.

b) **Production of Organic Compounds:** Fermentation (breakdown of carbohydrate in absence of oxygen) process of various bacteria produces organic compounds like lactic acid (by *Lactobacillus*), acetic acid (by *Acetobacter aceti*), acetone (by *Clostridium acetabutylicum*) etc.

c) **Fibre Retting:** The action of some bacteria like *Clostridium, Pseudomonas* etc. help in fibre retting i.e. separation of stem and leaf fibre of plants from other softer tissue.

d) **Curing:** The leaves of tea and tobacco, beans of coffee and coca are cured off their bitterness with the help of action of certain bacteria such as *Bacillus megatherium.*

e) **Production of Antibiotics:** Number of anti-bacterial and anti-fungal antibiotics such as Hamycin, Polymyxin, Trichomycin etc are obtained from mycelia bacteria (like *Streptomyces*). Similarly, Bacillus is used for production of antibiotics such as Bacitracin, Gramicidin etc

f) **Production of Vitamins:** Different kinds of vitamins are produced from bacteria like Riboflavin from *Clostridium butylicum,* Vitamin B12 from *Bacillus megatherium* and Vitamin K and B-complex from *Escherichia coli*.

1.3.3 General characteristics of Viruses

1) Viruses are exceptionally simple, filterable, obligate, intracellular particles capable of reproducing inside a living host.
2) These are extremely smaller in size (smaller than bacteria) and it ranges from 20 nm to 300 nm in diameter.
3) Inside a living, the viruses are active and they feed, reproduce, grow and move. But when they live outside, they remain inactive and behave as non- living things. They are also called living chemicals as they behave like chemicals and can be crystallized.
4) Viruses differ fundamentally from cellular organisms in that they contain only one type of nucleic acid either DNA or RNA. The nucleic acid may be single or double stranded DNA or RNA and occur in either linear or circular form.
5) Viruses do not contain cellular structures such as plasma membrane, mitochondria, Golgi complex, lysosomes, ribosomes etc.
6) Their basic structure consists of a protein coat, (capsid) and nucleic acid. The smallest viruses known as virioids, consists of a single strand of naked nucleic acid without protein coat. Capsid is made up of several identical protein subunits known as capsomeres. These subunits are usually arranged in the helical or polyhedral geometric forms which are specific for a particular virus.
7) The capsomeres, forming the capsid (protein coat) of a virus, are of two types: -Pentamer (made up of five identical monomers) and Hexamer (having six monomers). Each monomer is connected with the neighboring monomers on either side with the help of bonds. Similarly capsomeres are also connected with each other but the bonds between capsomeres are weaker.

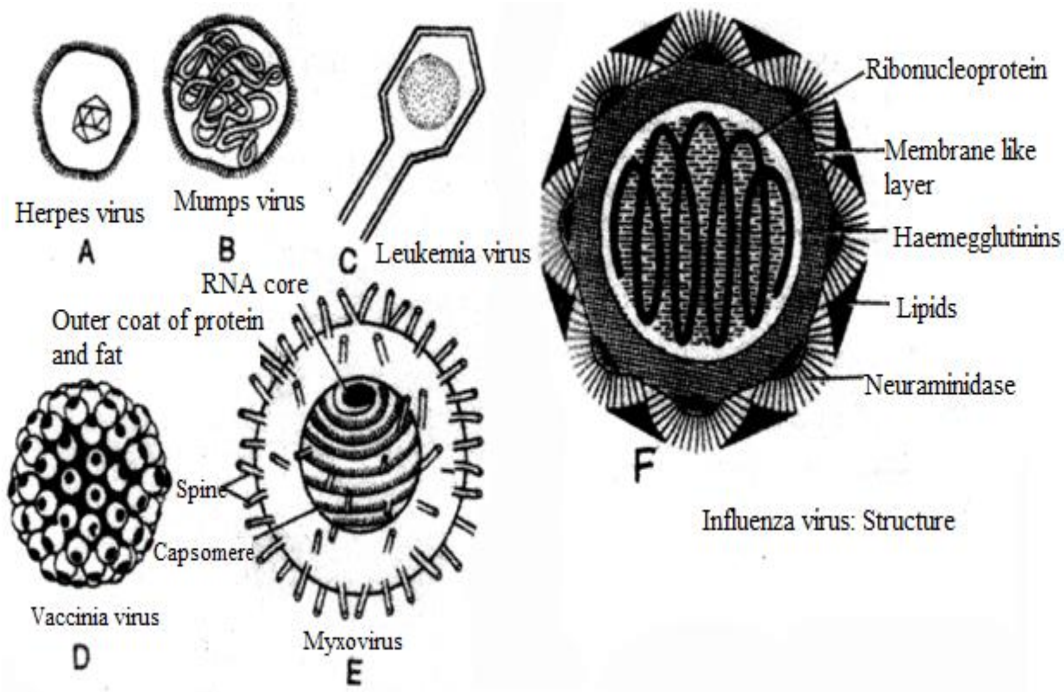


Fig.1.5. Different structures in Viruses

8) In complex forms (e.g., influenza and herpes virus and many plant viruses) the virus particles are surrounded by on outer envelope. The envelope is membranous and made up of protein, lipids and carbohydrates. Viruses with envelope are called enveloped and those without envelope are said to be naked (e.g., TMV) (Fig.1.5).
9) Viruses multiply by assembly line method. They do not divide. The cycle of multiplication include :
   - attachment of virus to host cell.
   - penetration by genetic material.
   - production of virus components by the cell.
   - assembly of new virus components by the cell.
   - release from the host cell.
10) They lack enzymes for most metabolic processes.
11) Viruses are also unique microorganisms as they lack machinery for the synthesis of proteins
12) They are obligate intracellular parasites of animals, (protozoa insects, fish, birds, amphibians, mammals and humans) or plants (angiosperms, gymnosperms, ferns, and fungi).
13) Many of the viruses have a close biological relationship with an arthropod or other type of vector on which they are dependent for their transmission from one host to the other.

14) The viruses cause very serious diseases in crop plants, ornamental plants and forests trees and many serious diseases in animals caused by viruses are well known since the time immemorial.

1.3.4 Economic importance of Viruses

Viruses are entities which infect all cellular forms eukaryotes (vertebrate animals, invertebrate animals, plants, fungi) and prokaryotes (bacteria and archaea). They are obligate parasites and reproduce only in living organisms. Therefore these organisms are very important and we need to understand the nature of viruses, how they replicate and how they cause disease. This knowledge permits the development of effective means for prevention, diagnosis and treatment of virus diseases through the production of vaccines, diagnostic reagents and techniques, and antiviral drugs. These medical applications constitute major aspects of the science of virology.

1.3.4.1 Negative impacts of viruses:

Veterinary virology and plant virology are also important because of the economic impact of many viruses that cause disease in domestic animals and crop plants: foot and mouth disease virus and rice yellow mottle virus are just two examples. Another area where viruses can cause economic damage is in the dairy industry, where phages can infect the lactic acid bacteria that are responsible for the fermentations that produce cheese, yogurt and other milk products. Viruses are important agents of many human diseases, ranging from the trivial (e.g. common colds) to the lethal (e.g. rabies), and viruses also play roles in the development of several types of cancer. Virus diseases can also affect the well-being of societies. Smallpox had a great impact in the past and AIDS is having a great impact today.

Different viral diseases attack different parts of the body

S.NO.	Viruses	Target parts/organisms	Source of spread
1	**Chicken virus and measles virus**	Cells of skin causing watery blisters and red rashes.	Direct or indirect contact
2	**Influenza virus**	Lining of nose and throat	Spread through direct contact, Spitting and coughing
3	**Polio virus**	Muscles	Infected faeces and flies
4	**HIV virus**	Immune system	Direct and sexual contact with

			an infected person.
5	**Tobacco mosaic virus**	Tobacco plant	Direct contact

1.3.4.2-Positive impact of viruses:

- **Phage typing of bacteria:** Some groups of bacteria, such as certain Salmonella species, are classified into strains on the basis of the spectrum of phages to which they are susceptible. Identification of the phage types of bacterial isolates can provide useful epidemiological information during outbreaks of disease caused by these bacteria.
- **Sources of enzymes:** A number of enzymes used in molecular biology are virus enzymes. Examples include reverse transcriptases from retroviruses and RNA polymerases from phages.
- **Pesticides:** Some insect pests are controlled with baculo viruses and myxoma virus is used to control rabbits.
- **Anti-bacterial agents:** In the mid-20th century phages were used to treat some bacterial infections of humans. Interest declined with the discovery of antibiotics, but has been renewed with the emergence of antibiotic-resistant strains of bacteria
- **Anti-cancer agents:** Genetically modified strains of viruses, such as herpes simplex virus and vaccinia virus, are being investigated for treatment of cancers. These strains have been modified so that they are able to infect and destroy specific tumor cells, and unable to infect normal cells.
- **Gene vectors for protein production:** Viruses such as certain baculo viruses and adenoviruses are used as vectors to take genes into animal cells growing in culture. This technology can be used to insert into the cells genes encoding useful proteins, such as vaccine components, and the cells can then be used for mass production of the proteins.
- **Gene vectors for treatment of genetic diseases:** Children with severe combined immunodeficiency (baby in the bubble syndrome) have been successfully treated using retroviruses as vectors to introduce into their stem cells a non-mutated copy of the mutated gene responsible for the disease.

1.3.5 General characteristics of Fungi

1) Fungi are achlorophyllous, non-vascular eukaryotic thallophytes.
2) They are non-green so heterotrophic microbes obtaining their food in a soluble form by uptake through plasma membrane.
3) Being heterotrophic, they live as parasites, saprophytes or symbionts.
4) They are ubiquitous in distribution and occur in any habitat where life is possible.
5) There are about 100,000 species of fungi.
6) Plant body of fungi typically consists of branched filamentous hyphae which form a network called mycelium. The hyphal structure is variously modified.
7) The hyphae are aseptate, multinucleate in lower forms while septate and uni, bi or multinucleate in higher forms (Fig.1.6).

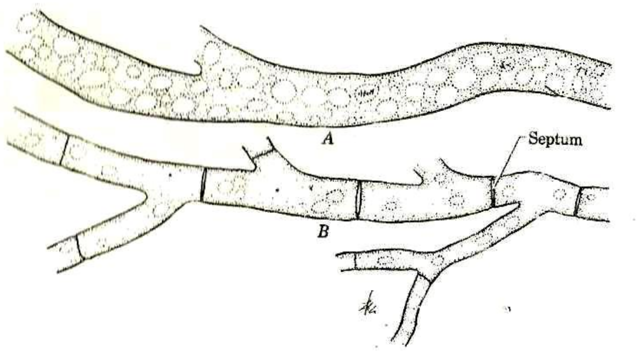


Fig.1.6: Somatic Hyphae. A. Coenocytic (nonseptate hyphae) B. Septate Hyphae

8) Protoplasm remains surrounded by a distinct cell wall made up of fungal cellulose known as chitin. But in primitive slime moulds cell wall is absent.
9) Fungi are entirely devoid of chlorophyll but carotenoids are normally present. Cytoplasm contains endoplasmic reticulum, mitochondria, Golgi bodies and many non-living substances like reserve food.
10) In lower fungi the reproductive cells (Asexual spores and gametes) are motile (uni or biflagellate). But the higher fungi lack motile cells and show gradual reduction of sexuality.
11) Flagella are two types (i) whiplash (acronematic) flagella are smooth and (2) Tinsel (pentonematic) flagella with numerous minute hairs like structures on their surface.
12) Fungi are heterotrophic due to absence of chlorophyll. So they have to depend for their food on others. Therefore they may beof the following types:
    (a) **Parasites** obtain their nutrition from other living plants or animals. Some of them live only on living protoplasm and are called obligate parasites. Whereas others can also

grow on dead organic matter in absence of living host and are known as facultative saprophytes.

(b) **Saprophytes** obtain their nutrition from the dead decaying organic matter. Among these, some saprophytes such as *Mucor* can obtain their nutrition only from dead organic matter and are known as obligate saprophytes. On the other hand some saprophytic fungi as *Fusarium* have the capacity to invade living organisms and are known as facultative parasites.

(c) **Symbionts** grow on other living organisms and both are mutually benefited. Such association is known as symbiosis, Lichens and mycorrhiza are common examples of this, in which fungal partner shows mutualistic relationship with alga and roots of higher plants respectively.

13) In unicellular fungi whole vegetative cell is transformed into a reproductive unit such fungi are known as Holocarpic while in most of the fungi only a part of the vegetative mycelium forms reproductive unit and rest remain vegetative. Such fungi are known as Eucarpic.

1) Fungi reproduce by vegetative, asexual and sexual means. Vegetative by fragmentation (e.g., *Rhizopus, Alternaria* etc.) fission (e.g., yeast) and budding (e.g. yeast and *Ustilago*) (Fig. 1.7). Asexual reproduction occurs during favourable condition by the formation of a variety of conidia and spores. Spores may be unicellular (e.g. *Aspergillus*) or multicellular (e.g. *Alternaria*). They may be endogenous (developed inside in pycnia or sporangia) or exogenous (developed outside on sporophores or conidiophores). Some common asexual spores in lower fungi are motile known as zoospores. (e.g., Phytophthora), Non motile known as aplanospores or conidia (e.g. *Mucor*, *Rhizopus*) (Fig. 1.8). In Higher fungi these non-motilespores are called conidia, oidia or chlamydospores.

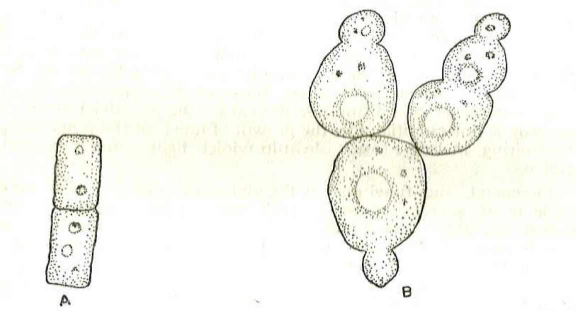


Fig.1.7: Asexual reproduction, A. Transverse cell division (fission) B. Budding

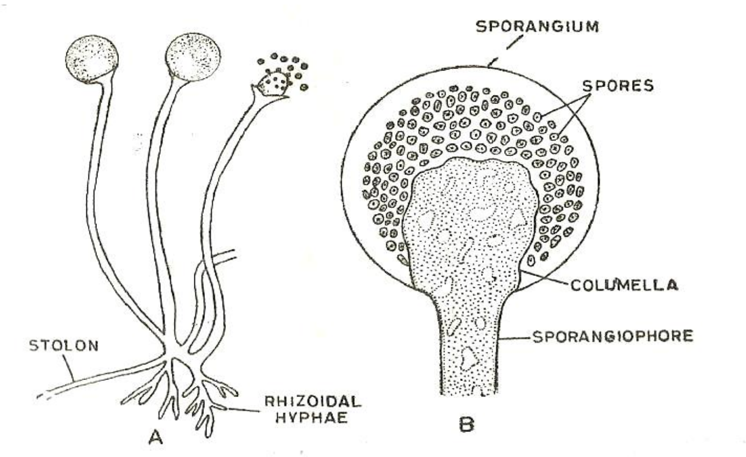


Fig. 1.8 Asexual reproduction. A. Endogenous spores of *Rhizopus* B. Sporangium of *Mucor*

2) Except for the class Deuteromycetes, sexual reproduction occurs in all groups of fungi. It is completed in three phases (a) Plasmogamy (fusion of protoplasm of two compatible gametes of sex cells) (b) karyogamy (fusion of two nuclei from two gametes to form Dikaryon). (c) Meiosis (after karyogamy reduction division takes place in diploid nucleus to form haploid stage). The sex organs if present are called gamentangia which may form gametes.
3) The various methods of sexual reproduction (by which the compatible nuclei are brought together for plasmogamy) are as follows:
   (a) Planogametic copulation (fusion of two naked motile gametes) May be either Isogamy (fusing gametes morphologically similar) or Anisogamy (fusing gametes are both morphologically and physiologically dissimilar) or Oogamy (fusion between female gamete (egg) and male gamete (antherozoid) (Fig. 1.9).

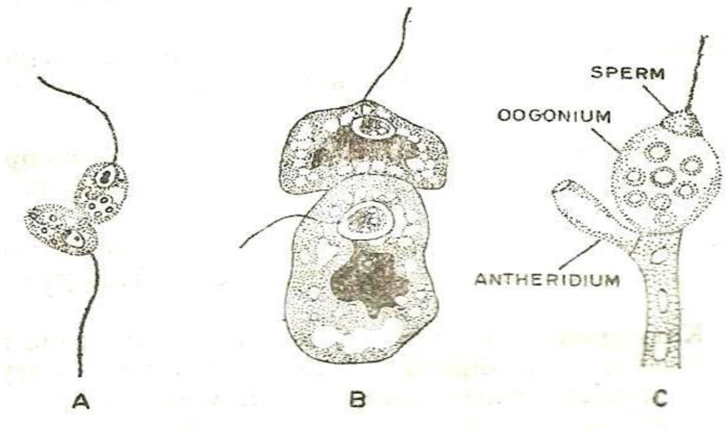
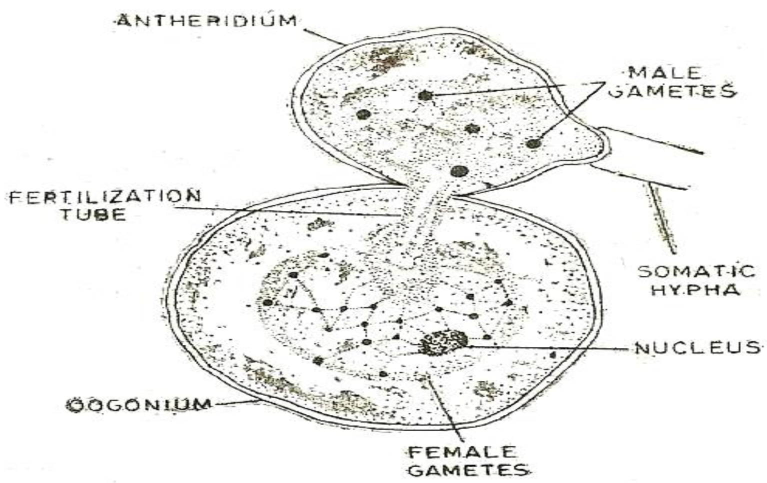


Fig. 1.9 Sexual reproduction, A. Isogametes; B. Anisogametes; C. Heterogametes

(b) Gametangial contact (Male and female gametangia come in close contact with the



help of a fertilization tube)(Fig. 1.10).

Fig.1.10 Sexual reproduction, Plasmogamy through gametangial contact in *Pythium* spp.

(c) Gametangial coupulation (Fusion of entire contents of two compatible gametangia) and formation of zygote which develops into a resting spore e.g., *Mucor*, *Rhizopus*.

(d) Spermatization (sex organs are completely absent and the sexual process is accomplished by minute spore like spermatia (male gamete) and specialized receptive hyphae (female gamete) e.g., *Puccinia*.

(e) Somatogamy (sex organs are not at all formed but two vegetative cells or two vegetative hyphae take over the sexual function and fuse together). e.g., *Morchella* and *Agaricus*.

4) The optimum temperature for the growth of fungi is between 20^0C to 30^0C.

5) Although light is not essential for growth, but for sporulation in many species, some light is necessary.

6) There are five basic types of life cycles in fungi as asexual, haploid, haploid-dikaryotic, haploid-diploid and diploid.

1.3.6 Economic importance of Fungi

The fungi are of great economic importance on account of their both harmful as well as beneficial effects. A large number of fungi cause destructive havoc to our valuable crop and timber plants, various types of food products. They also attack the live-stock as well as human beings. But, all of them are not harmful to the mankind, as most of the species bring about decomposition of dead bodies of plants and animals as well as of animal dung. In addition they are also useful in the production of new age medicines and other useful products.

There are several species of fungi which are of tremendous economic importance. They are beneficial as well as harmful to man.

(a) Beneficial activities of fungi

(i) Edible Fungi – Fungi provide us food that is rich in proteins. Dried yeasts contain about 50 per cent protein. Besides, they are rich in vitamin and B-complex. Mushrooms are generally members of Basidiomycetes. Fruiting bodies of some saprophytic mushrooms are edible; they are preferred for both their taste and food value. Most of the edible fungi are the members of Basidioycetes and Ascomycetes, for example:

Edible fungi of Ascomycetes-

- Saddle fungi – *Helvella* and *Gyromitra*
- Morels – *Morchella* and *Verpa*
- Truffles – Species of *Tuber* and *Cyttaria*

Edible fungi of Basidiomycetes -

- Jew's ear fungi – *Hirneola auriculajudae* adn *Hirneola polytricha*
- Mushrooms – Species of *Agaricus*
- Pore fungi – *Boletus*, *Strobilomyces* and *Fistulina*
- Teeth fungi – Species of *Hydnum*
- Giant puffball – *Clavatia mexima* and *Lycoperdon* species

(ii) Role of Fungi in Agriculture:

Fungi and nitrogen fixation – Some soil fungi are beneficial to agriculture because, a small amount of atmosphere nitrogen is also fixed by non-symbiotic fungi such as *Rhodotorula* and *Saccharomyces*.

Soil fertility – Some soil fungi maintain the fertility of soil. The saprophytic fungi particularly in acid soils where bacterial activity is at its minimum cause decay and decomposition of dead bodies of plants and their wastes taking up the complex organic compounds (cellulose and lignin) by secreting enzymes. The enzymes convert the fatty, carbohydrate and nitrogenous constituents into simpler compounds such as carbon dioxide, water, ammonia, hydrogen sulphide etc. Some of these return to the soil to form humus and rest to the air from where they can again be used as raw material for food synthesis. Some fungi like *Aspergillus*, *Cladosporium*, *Rhizopus*, *Penicillium*, etc. have soil binding property. This is achieved by the secretion of mucilaginous substances. Some common fungal inhabitants of the soil help to combat diseases caused by soil borne fungi. *Trichoderma lignorum* and *Gliocladium fimbriatum* are found in damp soils. They have an inhibitory effect on the growth of the mycelium of *Pythium*. They serve to suppress fungi causing the damping off disease of seedlings and thereby influence favourable the growth of crops. There are some predacious fungi in the soil. They trap and destroy the nematodes.

(iii) Role of Fungi in Industry:

Baking industry – *Saccharomyces cerevisiae* (yeast) popularly known as baker's yeast is widely used in baking industry. Alcoholic fermentation is the basis of baking industry, because the fermentation of sugar solutions by yeasts produces ethyl alcohol and carbon dioxide. Carbon dioxide is collected, solidified and sold as dry ice. In the baking industry CO2 is the useful product. It serves two purposes: (i) causes the dough to rise, (ii) makes the bread light.

Production of alcoholic beverages – The other by product of fermentation of sugar or malt solution is alcohol. The enzyme zymase present in yeast cells convert hexose sugars into alcohol.

Acid production – Several fungi are helpful in the commercial production of many organic acids, for example, *Aspergillus niger* in citric and oxalic acid, *A. Gallomyces* in gallic acid, *Penicillium purpurogenum* in gluconic acid, Mucor in fumeric acid, *Rhizopus oryzae* in lactic acid.

Enzyme production – Many fungi produce enzymes which have industrial uses, for example, amylase from *Aspergillus*, invertase from *Alternaria* and *Saccharomyces*, and zymase from *Saccharomyces*.

Cheese making – *Penicillium camemberti* adn *P. Roquefortie* are used in cheese making. These moulds add a special flavour to the cheese.

Vitamin extraction – the yeasts are the best sources of vitamin B complex, Vit. B12 is extracted from *Eremothecium ashbyji* and Vit. A from *Rhodotorula gracilis*.

Source of hormones – Gibberellins are plant hormones produced by the fungus *Gibberella fujikoroi* which causes a disease of rice accompanied by abnormal elongation. Gibberellin is used to accelerate growth of several horticultural crops.

(iv) Role of fungi in medicine – At present there are more than 700 fungal species which secrete antifungal and antibacterial substances. These substances are called antibiotics. The first antibiotic penicillin was extracted from *Penicillium notatum* by Sir Alexander Flemming, for which he was awarded Nobel Prize in 1945. Some important antibiotics and their sources are as follows:

	Antibiotics	Fungal source
I	Streptomycin	*Streptomyces griseus*
II	Penicillin	*Penicillium notatum and P. chrysogenum*
III	Ramycin	*Mucor rammannianus*
IV	Brefelidin	*Penicillium brefedianum*
V	Fumigallin	*Aspergillus fumigates*
VI	Clavacin	*Calvaria*
VI	Griseofulvin	*Penicillium griseofulvum*
VII	Ergotin	*Claviceps purpurea*

Some of the cholesterol and blood pressure lowering drugs are also obtained from certain fungi, e.g. mevastatin from *penicillium citrinum* and lovastatin from *monnascus ruber*.

(v) Fungi in Biological Research – Use of microorganisms in determining the potency of drugs, detection and estimation of various chemicals in given samples is known as the biological assay. Amongst fungi, *Aspergillus niger* is used to detect very minute quantities of Zn, Ca, Pb, Mn, Cu, etc. in given samples. *Neurospora* is an ideal material for genetic and biochemical studies. It is popularly known as ‘Drosophila of Plant Kingdom’, because of its suitability in the studies of biological sciences.

(b) Harmful activities of fungi

(i) Plant diseases – Fungi have a negative value because they are the causative agents of different diseases of our crop, fruit and other economic plants. These fungal diseases take a heavy toll and cause tremendous economic losses. Some important plant diseases and their causative agents are given in table.

Table:1- Some Important Plant Diseases

	Name of disease	Fungus
1.	Early blight of potato	*Alternaria solani*
2.	Late blight of potato	*Phytophthora infestans*
3.	Loose smut of oat	*Ustilago avenae*
4.	Brown leaf spot of rice	*Helminthosporium oryzae*
5.	Black or stem rust of wheat	*Puccinia graminis tritici*
6.	Loose smut of wheat	*Ustilago nuda tritici*
7.	Powdery mildew of wheat	*Erysiphe graminicola*
8.	Ergot of bajara	*Claviceps microcephala*
9.	Loose smut of barley	*Ustilago nuda hordei*
10.	White rust of crucifers	*Albugo candida*
11.	Green ear disease of bajara	*Sclerospora graminicola*
12.	Tikka disease of groundnut	*Cercospora arachidicola*

(ii) Deterioration of food and other articles – Saprophytic fungi for example *Rhizopus*, *Mucor*, *Aspergillus* grow on food articles such as bread, jam, pickles, and make them inedible. They also destroy leather articles. Tubber, wool and painted surfaces are also get damaged by species of *Aspergillus*, *Penicillium*, *Alternaria* and *Rhizopus*.

(iii) Decay of wood – In India the commercial timber yielding plants such as sal, teak, sisam are destroyed by *Polyporus*, *Ganoderma* etc. These fungi secrete cellulose and lignin decomposing enzymes and cause 'heart rot'.

(iv)Fungal toxins – Mushrooms like *Amanita phalloides*, *A. Virosa* are poisonous. Poisoning of these mushrooms causes abdominal pains with vomiting, sweats, diarrhoea etc. *Claviceps purpurea*, a parasitic fungus contains a powerful poison and causes gangrenes. LSD (Lysergic acid diethylamide), a hallucinogenic and hypnotic compound, is also obtained from *Claviceps*. Besides this, some fungi secrete a group of toxic/carcinogenic compound called aflatoxins.

(v) Human and animal diseases – Some species of *Aspergillus* such as *A. fumigates, A. flavus* and *A. niger* are human pathogens. They cause disease collectively known as aspergilloses. The symptoms of this disease are similar to tuberculosis. Many parasitic fungi Imperfecti live in the mucous membranes of throat, bronchi and lungs and cause infection of mouth and lungs. A few fungi cause serious diseases of domestic animals. Some fungal diseases of humans are given in table.

Table :2- Some Fungal Diseases of Humans

	Disease	Pathogen
1.	Ringworm	*Microsporon ianosum*
2.	Dobhi-itch	*Epidermophyton floceosum*
3.	Candidiasis	*Candida albicans*
4.	Athelete foot	*Trichophyton interdigitate*
5.	Blastomycosis	*Blastomyces dertimidis*
6.	Aspergilliosis	*Aspergillus flavus, A. Fumigates, A. Niger*
7.	Penicillosis	*Penicillium* sp.

1.3.7 General characteristics of Lichen

Lichen seems like a single organism, but actually it is a combination of two plants an alga and a fungus which live together in a symbiotic relationship. The algal component in the lichen is known as phycobiont and fungal component is called as mycobiont. The 90% part of the thallus (body of the lichen) is produced by the mycobiont. In lichen, the mycobiont produces a thallus and provides colour, shape and structure to the lichen with little contribution from algae. This fungal component mostly belongs to the group Ascomycetes, Deuteromycetes, or Basiodiomycetes of fungi. The alga supplies nutrients by photosynthesis, while the fungus protects the alga from excessive Sun rays and supplies water by absorbing water vapor from the air. It may be a type of relationship called a 'symbiosis' where both partners get benefitted.

History of Lichens: The word Lichen appeared 1600, and was drawn from the Greek 'leikhen', meaning 'what eats around itself'. The term 'Lichen' and this group of plants were introduced by Theophrastus, the father of botany. Those who studied lichen are called lichenologist. In 1867 Swiss botanist Simon Schwendener first proposed the theory of the duality of the lichen thallus. According to his theory, alga and fungus share a relationship as helotism where the Alga was slave providing nutrient to fungal master. In 1887 De-Bary used the term Symbiosis for association of lichen. Schwendener's dual theory of lichens has been accepted by every one for which experimental proof has been obtained.

1. Lichens are very common and widely distributed from the arctic to Antarctic regions of the world. They can survive in extremes of hot and cold weather. They are mostly xerophytic in nature and can endure long periods of drought, tough conditions of deserts and frozen soil of the artic region. Lichens may become dormant in unfavourable environmental conditions for some time and then they become metabolically active again on return of more friendly conditions. These plants can be found most frequently on stems, bark and trunks of trees, rocks, soil, lands, stones etc. Lichens do not have roots, thus they can grow in areas where no other vegetation is possible such as concrete, sand, stable rock surfaces etc. A few are unattached and blow about freely. Lichens are favoured by sufficient humidity, sunlight, still conditions and clear air. Most of the lichens generally depend on atmospheric sources for nutrition in feeding itself through photosynthesis in the algal cells.

2. On the basis of the nature of fungal part lichens are classified:

(i) Ascolichens: In this, the fungal component belongs to Ascomycetes. Such lichens are divided into two sub-groups-

a) Gymnocarpeae: In which fruiting body (i.e. ascocarp) is apothecium. e.g.- *Parmelia*

b) Pyrenocarpeae: In which the ascocarp is Perithicium type. e.g.- *Dermatocarpon*

(ii) Basidiolichens: in this, fungal component belongs to basidiomycetes. e.g. *Dictonema, Corella.*

3. On the basis of Algal component lichen are classified into two types:

(i) Homiomerous:In this, the algal component is distributed throughout the structure and the fungal part grows outside the thallus as a thin protective layer. e.g.- *Collema.*

(ii) Heteromerous: The algal component in a heteromerous is confined to a specific region. The heteromerous thallus can be differentiated into four distinct layers, three of which are formed by the fungus and one by the alga. e.g. *Parmelia, Xanthoria.*

4. Lichens are classified on the basis of growth forms:

(i) Crustose: These lichens have a flattened thallus, resembling crusts, generally grown on rocks or occasionally on the bark of trees holding tightly to their substrates and it is difficult to remove them without crumbling away. e.g.- *Haematomma lecanora, Graphis, Lacidia* etc.

(ii) Foliose: These lichens have a flat, expanded, leaf like thallus which spread out in a horizontal layer over the surface. They are attached by root-like threads and can be easily dismantled without damaging the substrates. e.g. - *Physcia, Parmelia, Gyrophora* etc.

(iii) Fruticose: These lichens have a thallus that is branched and bushy and can hang from the substrate. It may be erect or pendant. They can be removed from the surface by hand. e.g.-*Cladonia rangiferina, Usnea barbata* (Fig.1.11).

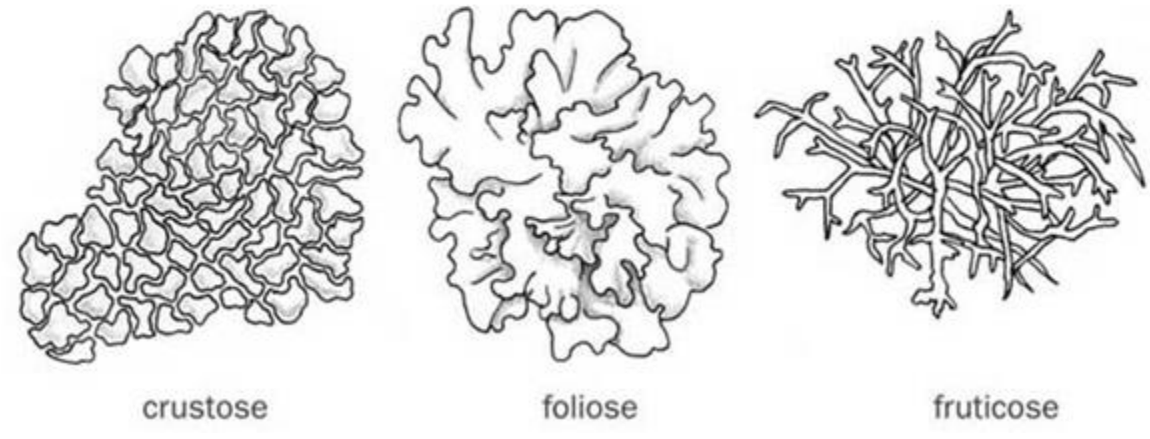


Fig.1.11- Lichens

5. Lichens possess simple type of internal structure. The plant body of Lichen is composed of hyphae of the fungus associated with the algal component. Internal Structure of Lichens is as follows:

(a) Upper cortex: It forms the upper most layer which is generally thick and protective in nature and consists of more or less vertical fungal hyphae. The fungal hyphae are compactly interwoven without any intercellular spaces to produce a tissue-like layer which is known as Plectenchyma or Pseudoparenchyma.

(b) Algal Zone: This zone lies beneath the upper cortex. This zone generally consists of blue-green algae. In this layer algal cells intermingled with loosely interwoven fungal hyphae. The algal zone is the photosynthetic region of the lichen thallus and was known as gonidia.

(c) Medulla: It is the central core of the thallus and is composed of loosely arranged fungal hyphae with intercellular spaces. It works as a water reservoir. Usually, the wall of the fungal hyphae is thick and strong. The hyphae run in all directions.

(d) Lower cortex: The lower cortex is below medulla. It is formed by fungal component and made up of compact hyphae. They may be parallel to perpendicular to the surface of the thallus (Fig.1.12).

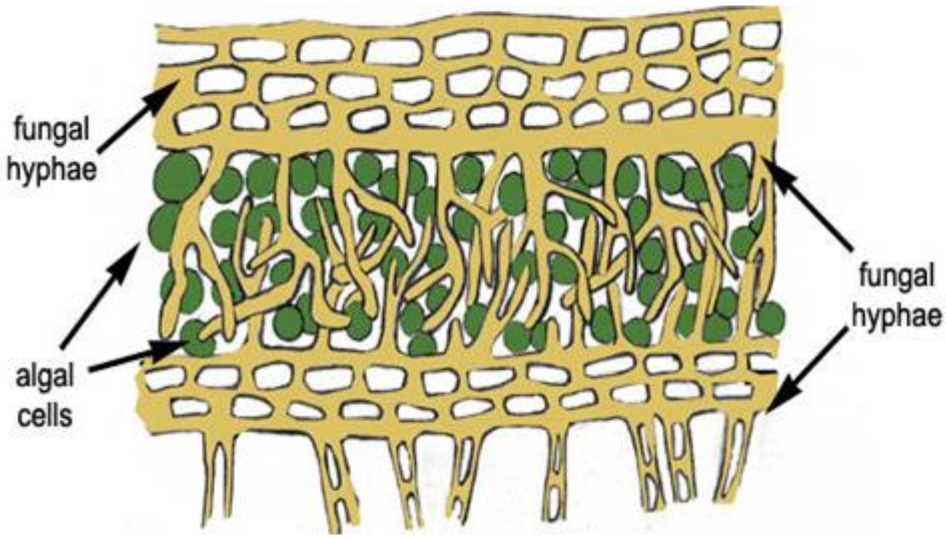


Fig.1.12: Internal structure of Lichen

6. The vegetative structures which are associated with the lichen thallus are:

(i) Breathing Pores: These are localized openings which develop in the upper cortex. The breathing pores serve for aeration and helps in respiration.

(ii) Cyphellae: The cup-like white spots present on the lower cortex in some foliose lichens are known as cyphellae. These cup-like breaks are formed of loosely arranged medullarly fungal hyphae. Their function is aeration.

(iii) Cephalodia: Cephalodia are small, dark-coloured, hard, gall-like swellings found in some species of lichens that contain cyanobacterial symbionts, the cyanobacteria may be held on the upper or lower surface of lichen thalli. The cephalodium consist of fungal hyphae and a few algal components.

(iv) Isidia: A coralloid out growths on the surface of a lichen thallus consisting of both fungal hyphae and algal cells. The main function of isidia is supposed to increase the photosynthetic surface of the lichen thallus. In terms of structure, isidia may vary in form in different lichen species as- cylindrical, warty, cigar shaped, clavate (club-shaped), scale-shaped, coralloid (coral-shaped), rod-shaped etc (Fig.8.3, 8.4).

7. Lichens show many colours. It can be red, oranges, yellow, green, white, grey etc. The colours vary due to presence or absence of special pigments. In the absence of special pigments, lichens are generally bright green to olive gray when it is wet and grey or grayish-green to brown when dry. This is because the cortex becomes more transparent and the underlying green photobiont layer becomes visible. Colours vary due to genetics, age and on the angle of exposure to light. Most widespread special pigments such as pale yellow usnic acid, give lichens a variety of colours as yellow, red, and orange.

8. Lichens get mineral nutrients from whatever they are growing upon. The fungus uses the hyphae to absorb food from its surroundings. The fungus gets benefits from the symbiotic relation because algae or cyanobacteria produce food by turning sunlight into energy through photosynthesis, water and minerals in their environment.

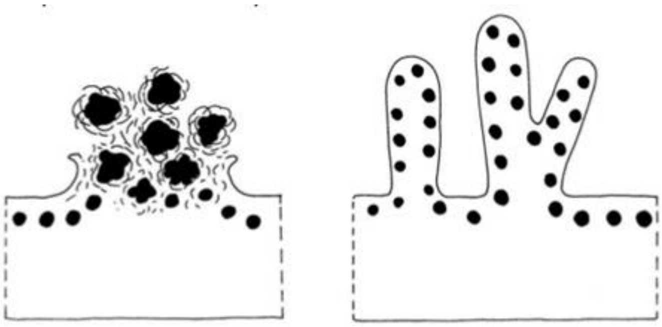
9. Lichens reproduce by following methods:

Vegetative Reproduction: Lichens may reproduce vegetatively by several methods (Fig.1.13).

(i) Fragmentation: A fragment broken off from a lichen thallus may grow into a new thallus.

(ii) Isidia: Isidia are tiny, simple, branched, spiny, elongated out growths from the thallus that break off or scattered by animals, wind and rain to new locations.

(iii) Soredia: These are minute, powdery granules or bud-like out growth present on the upper surface or edges of the thalli of many species of lichens.



Soredia Isidia

Fig.1.13: Vegetative structure

Asexual reproduction: Certain lichen produces large number of small non-motile spore-like structures, pycnidiospores. In certain species of lichens, the pycnidiospores are capable of germination. Each produces fungal hyphae and when it comes in contact with suitable algal cell, it develops into a new lichen thallus.

Sexual Reproduction: Only the fungal partner of the association reproduces sexually. The male reproductive organ is called spermogonium and the female is called as carpogonium or Ascogonium.

i) Spermogonia: The spermogonia develop in flask-shaped cavities on the upper surface of the thallus. Few of them are sterile and others are fertile. The fertile ones produce the non-motile male cells called spermatia. The spermatia are set free in a slimy mass through ostiole.

ii) Carpogonia: The carpogonium develops from hypha deep in the algal layer. It consists of two portions, the upper straight portion which is known as trichogyne and the lower coiled portion which is called ascogonium (oogonium). It is multicellular and the cells are uninucleate or multinucleate in some species. The basal cell of the ascogonium is fertile.

Fertilization: A spore called conidium is released from a pycnidia structure. Pycinidia are flask-like structures embedded in the thallus of the lichen. Conidia can act as "spermatia" in sexual reproduction of the lichen. The spermatia are functional male gametes. The male nucleus gradually passes downward to the oogonium, where it fuses with the female nucleus. Fused cell produces ascogenous hyphae within which develop 8 ascospores and asci. The hynenium is made up of Asci and Paraphysis. The fruiting body may be either apothecia. e.g. -*Parmelia* and Physcia or Perithecia e.g.-*Peltigera.*

In lichens, fruiting bodies are of following two types:

(i) Apothecia: Apothecia are variable in shape but commonly wide, open, saucer-shaped or cup shaped fruit body. Sometimes these may be plate-like and rarely does it have an elaborate form. (Fig.1.14).

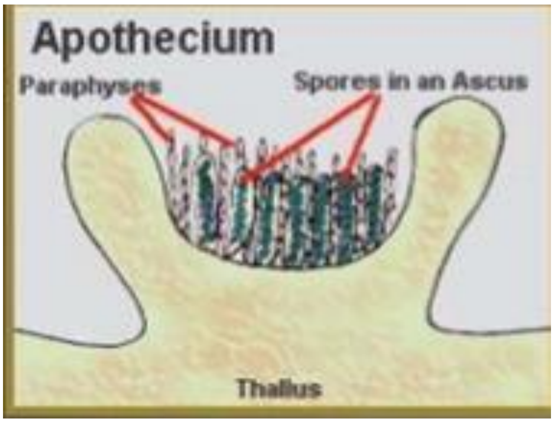


Fig.1.14: Apothecium

(ii) Perithecia: Perithecia are usually flask-shaped fruiting bodies containing the asci immersed in the lichen thallus tissue. Here the spore bearing body is much smaller in size than the apothecia and appear like black dots on the lichen surface. (Fig.1.15).

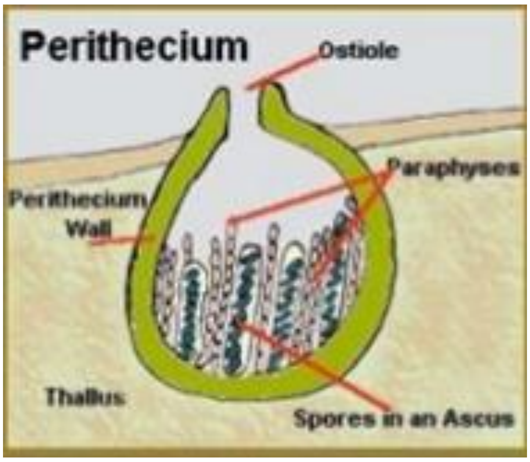


Fig.1.15: Perithecium

1.3.8 Economic importance of Lichens: Lichens are very important economically. Following are some examples of their importance:

1- **Medicinal Use:** A few species of lichens have been used in folk medicines for centuries as a cure for diarrhea, fever, jaundice, skin diseases, epilepsy etc. It is known that acids from various lichen can be useful in killing bacteria. *Labaria pulmonaria*is used in asthma and lung diseases, *Xanthoria parietina* for jaundice, *Peltigera canina* for dog bite. Usnic acid secreted from *Usnea barbata*, along with streptomycin is effective in tuberculosis. Lichen mass produces mucilaginous substance obtained from *Cetraria islandica* is used as laxative. *Cladonia pyxidata* is useful in whooping cough. Researches are yet to be conducted on many other medicinal benefits of lichens.*Peltigera canina* was used as medicine for hydrophobia in ancient time. *Parmelia saxatilis* is used to cure epilepsy. The Usnea and *Evernia furfuracea* are used as astringents.

2- Dyeing agent: Some lichens are useful as a natural source of dyes. The fungal components of certain species of lichens produce coloured pigments specially the red, brown, orange etc which can be extracted by boiling and used to dye fabrics and wood. Many lichens such as *Pocelia tinctoria* gives purple dyes which is used for centuries. Orchil is a blue dye obtained from *Cetraria icelandica* and *Lecanora* sp. which is used to dye wollen and silken clothes. Litmus is obtained from *Rocella montaignei* which is a commonly used dye in chemical laboratories as an acid-base indicator prior to the invention of the pH meter.

3- Food value: Certainspecies of lichens are consumed as food because they contain lichenin, a carbohydrate. Some lichens like *Cetraria islandica,Umbillcaria, lecnora* used are as food by human beings. *Cetraria islandica* is used as food by Eskimos and others. A species of *Parmelia* popularly known as rock flower (called as “rathapu” in telugu and “kallu huvu” in kannada) is used in curry preparation and is famous for its delicacy. It is prized as food in Southern India. *Evernia prunastri* was used by Egyptians as baking powder. Umbillicaria has been used as food in eastern Siberia. *Lecanora esculenta*, commonly called Manna lichen is used in desert tribes of Asia minor.

4- As Fodder: Lichens is important for some species of animals and small insects like snails, mites, caterpillar etc as source of food. Fruticose Lichen *Cladonia rangiferina* commonly known as Reindeer grass is used as food for horses and other animals. The other common used species for animals as fodder are *Labaria pulmonaria*, *Ramalina fastigiata, Ramalina fraxinea,* etc. Many lichens are consumed as food for insects and their larvae.

5- **Chemical Uses:** Lichen is useful in the brewing, distilling and tanning. Some Lichen species contain tannins and used in leather tanning industry. The lung wort lichen is used in tanning and brewing.

6- **Perfumes:** Sweet-scented thalli of some lichens are used in making perfumes, scents, dhup, hawan samagris, etc. It can retain the power of retaining the odor it is used. A lichen which is popularly known as an oak moss is used in perfumes as a fixative in Southern Europe. It is reported that some lichens like *Ramalina* and *Evernia* have perfumed volatile oils, which is used in manufacture of comestics.

Harmful effects of Lichens:

1- Lichens may have adverse effects on plants. Small fruit trees, Sandal wood trees, small shrubs densely covered with lichens could be damaged. Many epiphytic lichens can have harmful effects on the host plant.

2- A very few lichens are poisonous. These lichens are known to contain vulpinic acid and usnic acid, e.g. *Vulpicida* and *Letharia*. These lichens are yellow due to high concentrations of bright yellow toxin vulpinic acid. The wolf lichen (*Letharia vulpine*) got its name because it was used in Europe to poison wolves.

3- In dry season sometimes long threads of pendant lichens as *Usnea barbata* help in spreading of forest fire.

Ecological importance

Lichen is regarded as the "Pioneers of vegetation". They are capable of colonizing bare rocks. These plants play very important role in the ecological formation of soil. The organic acids secreted by lichens gradually dissolve and disintegrate the rocks into soil particles over which they grow. Mosses are the successors of the crustaceous rocks. When the lichens die and decay they contribute organic matter to the soil, improve the soil fertility so that other plants can grow on it. Having root-like structure lichens can anchor themselves to the soil. When there is occasional rainfall, comes the shower of rain is absorbed by the lichen thalli and often slow down the flow of water. It works as a barrier between the intense down pours and the soil. Lichens can enrich the soil by trapping water to support a active life over long dry spells.

Lichen as Bio-indicators or pollution indicators: Lichens are able to survive in extreme climates but they are very sensitive to air pollution. Fruticose lichen is the most vulnerable and Crustose is the least vulnerable lichen type to air pollution. Because lichens are pollution- sensitive so they can provide the valuable information about the environment. Lichens absorb everything from the air, including chemicals like carbon, sulfur, heavy metals into their thallus. Environmental scientists can extract the toxins from lichens and monitor the intensity of air pollution. Presence of lichens in abundance in a particular area is a indicator of non-polluted environment of the area whereas the declined growth of lichen at a site is an early warning sign of air pollution.

A Source of Nitrogen: Nitrogen is a nutrient which is important for living organisms. Some lichens are able to convert nitrogen in the air into nitrates and then secrete it into the soil. When it rains, nitrate is secreted into the soil and it can be useful for plants.

1.4 SUMMARY

Microbiology is the study of microorganisms. Microorganisms are too small to be seen with the naked eye. Microbes are widely distributed and are omnipresent. They can be isolated from air, water, soil, in living plants and animals and dead organic substances. Microorganisms include viruses, bacteria, algae, fungi and lichens.

Bacteria are small microscopic and least differentiated microorganisms. These are believed to be amongst the first primitive organisms on the earth possessing typical prokaryotic cell organization. They are omnipresent, and are unicellular and may live in association with others in colonies. They exhibit a variety of shapes e.g., spheres (coccus), rods (bacillus), spirals (spirillum), curved (vibrio), etc. Bacteria play important roles in different fields such as agriculture, dairy industry, organic compound production, antibiotics production, vitamins production, fibre retting, etc.

Fungi are achlorophyllous, non-vascular eukaryotic thallophytes. They are non-green so heterotrophic microbes obtaining their food in a soluble form by uptake through plasma membrane. Being heterotrophic, they live as parasites, saprophytes or symbionts. There are several species of fungi which are of tremendous economic importance. They are beneficial as well as harmful to man. Most of the fungi are edible and are rich in vitamin and B-complex. Some soil fungi are beneficial to agriculture, they fix a small amount of atmosphere nitrogen and maintain soil fertility. Fungi are also used in baking industry, production of alcoholic beverages, cheese making, vitamin extraction, in medicine, etc.

Lichen is a combination of two plants an alga and a fungus which live together in a symbiotic relationship. The algal component in the lichen is known as phycobiont and fungal component is called as mycobiont. Lichens may be crustose, foliose, fruticose. Mode of reproduction in lichens may be vegetative, asexual or sexual. Lichens are very important for mankind. They are used for different purposes *viz.* medicinally, as dyeing agent, for its food values, as fodder, in perfumes. They are also used ecologically as bio-indicators or pollution indicators and as a source of nitrogen.

1.5 GLOSSARY

Acervulus (pl. Acervuli): a mat of hyphae giving rise to short conidiophores closely packed together forming a bed-like mass.

Aerobe: An organism capable of living only in the presence of oxygen.

Anaerobe: An organism capable of living in the absence of free oxygen.

Antibiotic: A substance of microbial origin that has antimicrobial activity and it kills the other micrograms.

Apothecium: cup shaped ascocarp. Hymenium is exposed at maturity.

Apothecium: A disc-shaped structure that contains the asci, especially in lichens, a type of ascocarp.

Archaebacteria: A group of bacteria that includes primitive type of bacteria in which cell wall lack muramic acid.

Ascocarp: a fruiting body containing one or more asci.

Ascocarp: mature fruiting body of an ascomycetous fungus.

Ascospore: a sexual spore formed following meiosis in an ascus.

Ascospore: A meiospore borne in an ascus.

Ascus (asci): a sac-like cell generally containing a definite number of ascospores, typically 8, formed after karyogamy and meiosis.

Ascus: The sac or bag-like structure in which ascospores are formed.

Asexual: mitotic reproduction, not involving fusion of nuclei and meiosis, offspring the same as the single parent.

Bacillus: A rod shaped bacterium.

Bacteriophage: A virus whose host is a bacterium and replicates within bacterial cell.

Basidiocarp: a fruiting body that bears basidia.

Basidiospore: a sexual spore formed following meiosis, borne on a basidium.

Basidium (basidia): a structure bearing on its surface a definite number of basidiospores (usually four) that are formed following karyogamy and meiosis.

Biofertilizers: The nutrients of biological origin added to the soil to enrich the soil fertility are called biofertilizers.

Conidiophore: a simple or branched hyphae arising from somatic hyphae which bears at its tip or sides, cells which form or become conidia.

Conidium (pl. conidia or conidiospore): a nonmotile asexual spore formed on a conidiophore, formed from or as an extension of the hyphal walls. May be single or multicelled, simple or complex, round, elongated or spiral in shape. Found only in the Ascomycota or Basidiomycota.

Conidium: An asexual fungal spore.

Cynobacteria: blue-green algae.

Denitrification : The decomposition of nitrate from the surrounding through bacteria during anaerobic respiration.

Ectomycorrhiza: type of mycorrhiza in which fungal hyphae grow around the root and between cells of the epidermis.

Endophyte: general term to describe a fungus which lives within healthy plant tissue. May specifically refer to Balansioid fungi colonising grass leaves.

Eubacteria: True bacteria in which cell wall contain muramic acid.

Filamentous: Stringy or matted hair like.

Flagellum (pl. flagella): fine long thread projecting from a cell having a lashing or undulating motion which enables the cell to move when in water.

Haustorium: a specialised hyphal invagination of plant cells.

Heterokaryotic: a mycelium which contains genetically different mating types.

Heterothallic: a fungus which requires two different mating types to form sexual fruiting bodies.

Hyphae: Fungal filaments collectively called hyphae which form a thallus.

Imperfect stage: the asexual stage of a life cycle.

Karyogamy: fusion of two nuclei.

Metabolism: The net result of the biochemical processes of a living organism or cells.

Mycelium: mass of hyphae constituting the body of the thallus or fungus.

Mycobiant: The fungal partner in a lichen.

Mycorrhiza: mutually beneficial association between plant root and fungus.

Mycorrhiza: A symbiotic association between fungus and plant roots.

Pathogens: An organism able to cause disease. The term restricted to living organisms.

Perithecium: a closed ascocarp with a true wall and an ostiolate opening.

Perithecium: A flask shaped sexual reproductive structure that produces spores.

Phycobiont: algal partner in lichen.

Prions: Proteinaceous rod shaped infectious particles without nucleic acid.

Pycnidium: an asexual fruiting body that is hollow, and partially lined inside with conidiophores.

Symbionts: Two organisms living together with mutual benefits.

Symbiotic: Where both the partners get the mutual benefit by living together.

Taxonomy : The study of the principles and practices of classification of living things.

VAM: Vesicular Arbuscular Mycorrhizal fungi. These are also called endomycorrhiza.

Virioids: Small naked RNA molecule.

Yoghurt: Fermented liquor made from milk.

Zygote: cell in which two nuclei of opposite mating type have fused.

1.6 REFERENCES AND SUGGESTED READINGS

- Atlas, R.M. Principle of Microbiology.
- Bhagat Singh and Renu Singh, 2011. Microbiology for Medical Sciences. I.K. International Publishing House Pvt. Ltd. New Delhi.
- Casida, L.E. 1968, Industrial Microbiology, John Wiley and sons, New York.
- Clifton, A. 1958, Introduction to the Bacteria, MC Graw, Hill Book Co. New York.
- Doelle, H.W. and C.G., Heden 1986. Applied Microbiology, Kluwer Academic Press, London.
- Dubey, R.C. & D.K. Maheshwari. A text book of Microbiology. S.Chand & Co. New Delhi.
- Frazier, W.C. & D.C. Westhoff. 1988. Food Microbiology. Tata McGraw Hill.
- Kaushik, P. 1996, Introductory Microbiology. Emkay Publ. Delhi.
- Mandahar, C.L. 1978, Introduction to Plant viruses. S. Chand & Co. Ltd., Delhi.
- Mukherjee, K.G., and Ved Pal Singh, 1997. Frontiers in Applied Microbiology, Rastogi Publ. Meerut.
- Norris, J.R. and D.W. Ribbons 1970. Methods in Microbiology. Academic Press, London.
- Pelezar, M.J. Chan, ECS and Kreig, N.R. 1993, Microbiology, concept and Applications. M.C. Graw Hill, New York.
- Power, C.B. and H.F. Daginawala, 1970. Methods in Applied Microbiology, Rastogi Publ. Meerut.

- Prescott, I. J., J.P.M. Harley & A.D. Klein, Microbiology. Tata MC Graw Hill.
- Robinson, R.K., 1990. Dairy Microbiology, Elsevier Applied Sciences, London.
- Ananthanarayan & Panicker, 1997. Text Book of Microbiology Orient Longman.
- Bhagat Singh and Renu Singh, 2011.Microbiology for Medical Sciences I.K. International Publishing House Pvt. Ltd. New Delhi.
- Dubey, R.C. & D.K. Maheshwari. A Text Book of Microbiology. S. Chand & Co. Delhi.
- Kaushik, P. 1996. Introductory Microbiology. Emkay Publ. Delhi.
- Mandahar, C.L. 1978. Introduction to Plant viruses. S. Chand & Co. Ltd., Delhi.
- Subbarao, N.S. 1994. Soil Microorganisms & Plant Growth. Oxford & IBH Pvt. Ltd. New Delhi.

1.7 TERMINAL QUESTIONS

1. Give an account of general characteristics of bacteria, fungi and lichens.
2. Write notes on the following:
   (i) Economic importance of bacteria
   (ii) Economic importance of fungi
   (iii) Economic importance of lichen
   (iv) Harmful effects of lichens
3. Write short notes on the following:
   (i) Different shapes of bacteria
   (ii) Flagellation in bacteria
   (iii) Role of bacteria in industry and agriculture
   (iv) Sexual and asexual reproduction in fungi
   (v) Classification of lichens on the basis of growth forms
4. Discuss the economic importance and harmful effects of fungi in detail.
5. Briefly discuss reproduction in lichens.
6. Write an essay on the economic importance of bacteria, fungi and lichens.

UNIT 2- PHYCOLOGY AND BRYOLOGY

Contents:

2.1 OBJECTIVES

After going through this unit you will able to know

- General characteristics of algae and bryophytes
- Economic importance of algae and bryophytes

2.2 INTRODUCTION

'Algae'- a Latin word which literally means sea weeds. Phycologists however, use the term algae in common manner for all the classes of algae. They are thalloid **autotrophic organism** which can synthesize their own food by the process of photosynthesis in the presence of chlorophyll and sun light. The study of algae is known as **Phycology.** Various Indian and international phycologists have worked on algae. Amongst them R.N.Singh, M.O.P. Iyengar, H.D.Kumar, M.S.Randhawa (all are Indians), F.E. Fritsch and G.M Smith are known for their valuable contributions**. M.O.P. Iyengar** is known as "father of Phycology" **in India** and **F.E. Fritsch is known as "father of Phycology".**

Bryophytes are simple and primitive members of the plant kingdom. They are small (largest *Dawsonia,* may reach a height of 40 to 70 cm), inconspicuous green plants. They usually grow in tufts and cushions and contribute green colour to the mountains, forests and moors in rainy season. They are the simplest, truly land-inhabiting plants and restricted to moist and shady places. They are regarded as incompletely adapted to land conditions, because almost all of them still require water for the act of fertilization. Most of them also require sufficient moisture for vigorous growth. Because of the requirement of water to complete their life cycle, they are called "Amphibians" of plant kingdom.

2.3 GENERAL CHARACTERSTICS OF ALGAE

Algae are chlorophyll bearing autotrophic organisms having a **thalloid plant** body i.e., the plant body is not differentiated into root, leaf and stem. The thallus is **non vascular** therefore have no element for the transport of fluids. Algae have simple reproductive structure, sex organ are unicellular and if multicellular all the cells are fertile. Sex organs also lack a sterile jacket of cells around the reproductive cell and no embryo is formed after the fertilization.
They occur in a variety of habitat but mostly they are aquatic. They show distinct alteration of generation.

2.3.1 Occurrence and distribution (Algal habitat)

The algae are predominantly aquatic and are found in both fresh and marine water. Some are terrestrial and can grow under the soil surface damp and shaded sides. So, on the basis of habitat they may be classified in the following type.

A. Aquatic algae
B. Terrestrial algae
C. Algae of unusual habitats

A. Aquatic algae – Majority of algae are aquatic and found either in fresh water or in salty or marine water. The aquatic algae are either free floating or attached to the substratum with the help of holdfast.

1) **Fresh water algae**- These forms occur in fresh water of ponds, pools, lakes, streams, river etc. these fresh water forms may be present in slow running water e.g., *Cladophora, Oedogonium, Chara* or in stagnant or still water e.g., *Hydrodictyon, Chlamydomanas.*
2) **Marine water algae**-These algae occur in saline water of sea. Most of the members of class Phaeophyceae and Rhodophyceae are found in marine water. Marine algae are generally macroscopic having large thalli and commonly known as "sea weeds". Examples of marine forms are *Ectocarpus, Sargassum, Fucus, Laminaria.*
3) **Planktonic algae-** Floating forms of algae are generally referred as planktonic forms. These forms may be uniformly distributed in water or may be discontinuous and patchy in pitches both horizontally and vertically. The examples of fresh water planktonic algae are *Chlorella, Hydrodictyon, Chlamydomonas, Volvox,* while *Cyclotella, Hemidiscus, Fragillaria, Trichodesmium, Ocillatoria* are the example of marine water planktonic form. The abundant growth of planktonic algae imparts color and odor to the water. Such a phenomenon is called water- bloom or algal bloom. Formation of algal blooms fairly depends upon the factors like temperature, longer days and nutrient availability.

B. Terrestrial algae- Many algal genera are found on or beneath the moist soil surface and are called terrestrial algae. The algal forms also occur on the surface of soil e.g., few species of ***Vaucheria, Botrydium, Fristchilla*** while some algae having subterranean habit e.g., few species of ***Nostoc, Anabaena*** and ***Euglena*** and these are known as Cryptophytes.

1) **Aerophytes**: Such algal forms are adapted for aerial mode of life and occur on the tree trunks, moist walls, flower pots, rocks, fencing wires and get their water and carbon dioxide requirement directly from atmosphere are called Aerophytes.
2) **Cryophytes**: Algae growing on the mountain peaks covered with snow are called cryophytic algae. These algae impart attractive colours to the mountains. ***Haematococcus nivalis*** gives red colour to the arctic and alpine regions while ***Chlamyodomanas yellowstonesis*** gives yellow green colour to the snow of the mountains of European countries particularly in Arctic region.
3) **Thermophytes**: The algal genera occurring in hot springs at quite high temperature. There are some algae which are known to tolerate the temperature upto $85^{\mathbf{0}}$ C. ***Oscillatoria brevis,*** and ***Haplosiphon lignosum*** are example of thermophytes which survive upto temperature of 70^{0}C at which plant life is not possible. Majority of thermal algae belong to Myxophyceae.
4) **Lithophytes**: The algae growing attached to stone and rocky surface are called lithophytes. Usually the members of Cyanophyceae grow on moist rock, wet wall and other rocky surface e.g. *Nostoc, Rivularia.*

C. Algae of unusual form

1) **Epiphytes**- Such algal form which grow on the other plants are called epiphytic algae. These algae do not obtain food from plants on which they grow, rather require support only. *Coleochaete* in association with *Chara* and *Nitella* while *Chaetophora* on leaves of *Vallisnaria* and *Nelumbo, Oedogonium* on *Hydrilla* are seen frequently growing in natures as epiphytes.
2) **Halophytes**: Certain algae inhabit in water with high percentage of salts are called halophytes. They include *Chlamydomonas chrenbergii, Dunaliella* and *Stephanoptera.*
3) **Symbionts**: A large number of algae live in association with dissimilar organisms for their mutual advantage and are called symbiotic algae. The common examples of such association are the presence of *Nostoc* in *Anthoceros*, *Anabaena* in the coralloid root of *Cycas*, *Anabaena azollae in Azolla.* Lichen is one of the best examples of symbiosis where the association lies in between algae and fungi.
4) **Epizoic**: Many algae grow on the shells of Mollusces, turtles and fins of fishes and are called epizoic algae. e.g., *Cladophora* is found on snails and shells of bivalves while *Protoderma* and *Basicladia* grow on the back of turtle.
5) **Endozoic**: Algae which are found inside the body of aquatic animal is called endozoic algae. *Zoochlorellae* occur in the coelom (body cavity) of hydra and several other invertebrates. *Zooxanthella* lives in intimate association with coral community.
6) **Parasitic algae**: Few algae depend on other plants for obtaining food; these are termed as parasitic algae. The common intercellular parasitic algae is *Cephaleuros* which grow on the leaves of the tea plant (*Thea sinesnsis*) and cause the red rust disease of tea.

2.3.2 Organisation of thallus

Algal thalli range from unicellular microscopic structure to large sea weeds (macro algae) such as giant kelp which is more than one hundred feet in length. The thallus organization among algae shows a wide range of variation. One extreme is represented by a simple motile unicell (*Chlamydomonas*) or non motile unicell (*Chlorella*), while in some; cells are grouped into aggregations called colonies. (*Volvox*, *Pediastrum*). These colonies are again may be motile or non motile (*Hydrodictyon*). If a colony has a definite shape it is known as **coenobium** (*Volvox*). The filamentous habit is most elementary type of thallus and are multicellular. These filaments may be unbranched. e.g., *Ulothrix* or simple branched e.g., *Cladophora* or a highly complex e.g., *Ectocarpus, polysiphonia, Sargassum, Laminaria*. It is noteworthy that no single type of thallus is restricted to any particular division and there exists a striking parallelism among different division of algae. Detail of thallus organization you will study in unit 3.

There are two types of cell structures present in algae-

A. Prokaryotic cell
B. Eukaryotic cell

2.3.3 Prokaryotic cell

The prokaryotic cell organization is found only in class Cyanophyceae (Mixophyceae). The characteristic feature of prokaryotic algae is the presence of primitive or incipient nucleus, in this type of nucleus nuclear membrane and histones (the basic protein) are absent. The DNA consists of fibrils which may extend throughout the cell or concentrated in the central part. The chlorophyll pigment is found in the photosynthetic lamellae or thylakoids which may arrange in parallel layer in the periphery of the cytoplasm or form a network extending throughout the cell cytoplasm. The chloroplast, mitochondria, Golgi body and endoplasmic reticulum (the membrane bound organelle) are absent. The simple cells of blue green algae which lack a nuclear membrane, mitochondria, plastids and do not divide by mitosis are called prokaryotic. The cell wall is made up of mucopeptide, a specific strengthening component not found in cell walls of other algae (Fig. 2.1).

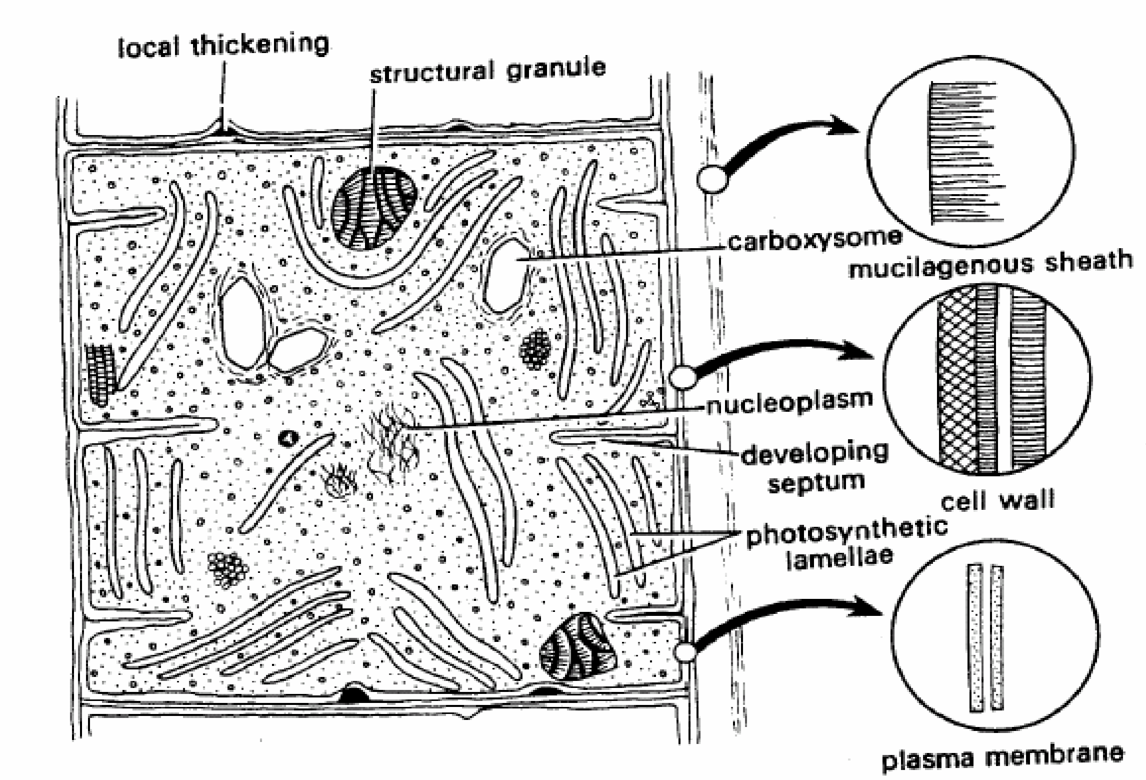


Fig 2.1: A detailed structure of Prokaryotic cell (Cyanophycean cell)

2.3.4 Eukaryotic cell

The eukaryoti**c** cell is characterized b**y** the presence of well organized nucleus and membrane bounded organelles like plastids, mitochondria and Golgi bodies (Fig 2.2).

2.3.5 Nucleus

The nucleus is having a well developed nuclear membrane which separates it from cytoplasm and it divides by mitosis. Algal cell may be uninucleated or multinucleated (**coenocytic).** Each nucleus contains one or more dark stained nucleoli or endosomes. There are four different types of nuclear structure found in algae are: a single nucleolus per nucleus, two or more distinct nucleoli per nucleus, a complex nuclear mass and a linear association of large number of small nucleoli.

2.3.6 Golgi bodies

Golgi bodies are composed of 2-20 flat vesicles. These are arranged in stacks (Dictysomes). The Golgi bodies are associated with the synthesis of cell metabolites and have also been shown to contribute to the plasma membrane as in higher plants.

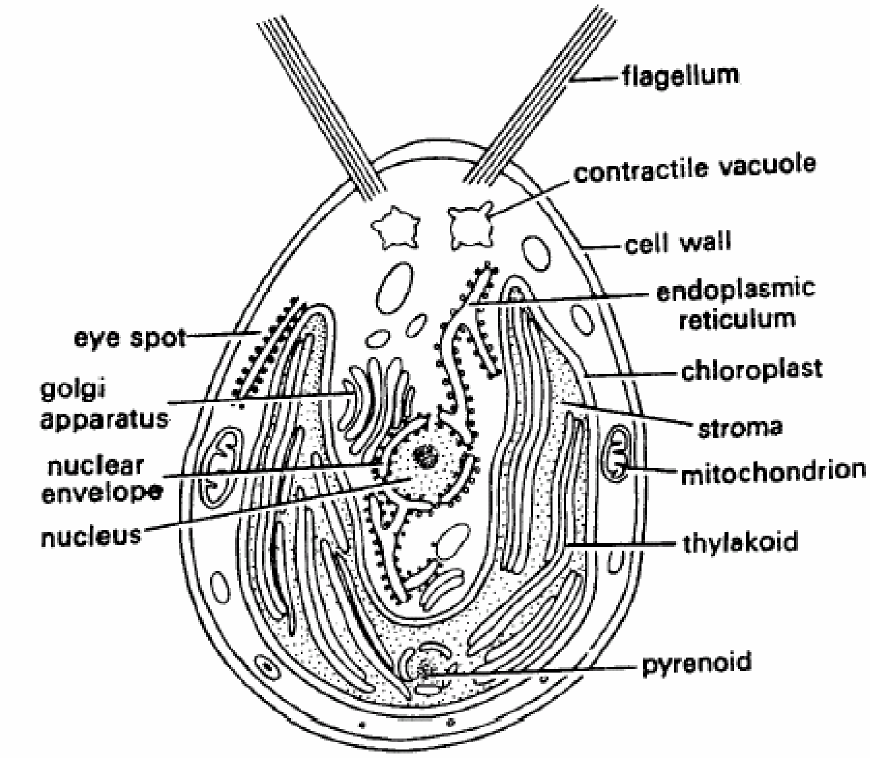


Fig 2.2: A Typical Eukaryotic Cell of Algae

2.3.7 Mitochondria

The respiratory enzymes are located in mitochondria so act as respiratory center of the cells. Mitochondria are also a site of enzyme action in protein synthesis and amino acid conversion. Mitochondria are also known as power house of the cell.

2.3.8 Endoplasmic reticulum

The cytoplasm of the algal cell is traversed by a system of interconnecting tubules called endoplasmic reticulum. The surface of endoplasmic reticulum has ribosomes, the sites of protein synthesis in the cell.

2.3.9 Eye spot

The motile vegetative and reproductive cells of algae have a pigmented spot called eye spot. The eye spot is considered to be light sensitive organelle which directs the movement of swimming cell (Fig 2.3).

On the basis of their position and structure, there are five types of eye spots:

- **Type A**- Eye spot is located in the chloroplast and it has no association with flagella.
- **Type B**- Eye spot is located in the chloroplast and associated with a swollen flagellum.
- **Type C**- Eye spot is an independent clusters of osmophilic granules and are situated at anterior side of cell.

- **Type D**-Eye spot having osmophilic granular structure with membranous lamella. It is present near flagellar bases.
- **Type E**-Eye spot having a lens, retinoid and pigmented cup.

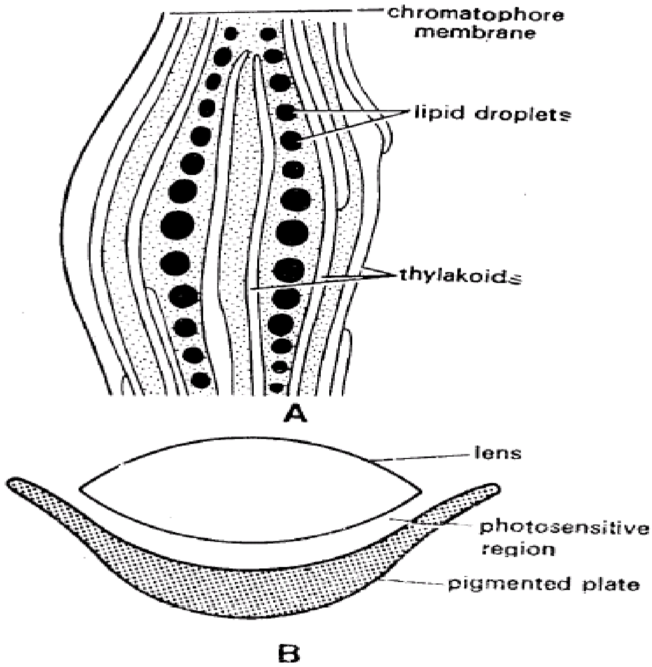


Fig 2.3: Eye spot in algae A- *Chlamydomonas* with thylakoids & B - *Volvox*

2.3.10 Vacuoles

The vacuole is bounded by a distinct membrane called tonoplast. There are two types of vacuoles:

- **Simple or contractile vacuoles-** These vacuoles show periodic contraction and throughout waste product out of cell and it has a secretary function.
- **Complex vacuoles**- A complex vacuole consists of a tube like cytopharynx, a large reservoir, and a group of vacuoles of different sizes.

Vacuoles act as the main osmoregulatory organ in the cell and help in regulating the absorption of water and solutes.

2.3.11 Pyrenoid

Pyrenoids are additional cell organelles present within or on the surface of chloroplast or chromatophore. They are **proteinaceous bodies** made up of densely packed proteinaceous fibrils and are the site of accumulation and synthesis of starch. In some algae the pyrenoids are transient structure, found only in certain stages. There may be single pyrenoid as in ***Chlamydomonas* or more than one as *in Oedogonium and Spirogyra.* Pyrenoids are invariably absent in class cyanophyceae.**

2.3.12 Flagella

Flagella are (singular Flagellum) the thread like structure concerned with cell movement and found in almost all the classes of algae except Rhodophyceae and Cyanophyceae. Each flagellum consists of 2 central fibrils surrounded by 9 peripheral double fibrils (9+2 arrangements) (Fig.2.4). A cell having flagella is also known as motile cell.

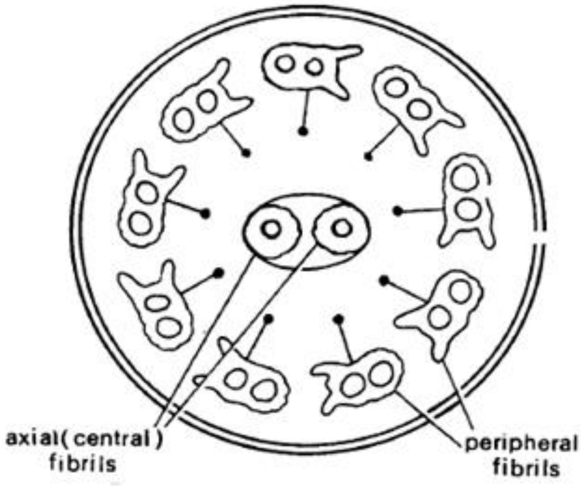


Fig.2.4: T.S of Flagella showing 9+2 arrangements of fibrils

There are mainly two types of flagella found in algae

A. Whiplash or acronematic flagella-Flagella having a smooth surface (Fig 2.5 A & B).

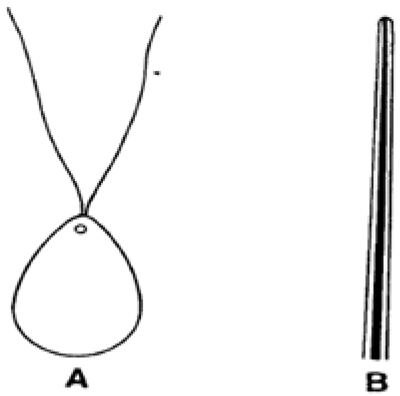


Fig.2.5: (A & B) Whiplash or acronematic flagella

B. Tinsel flagella or pleuromematic flagella-Here the surface of flagella is covered with fine hair like appendages called **mastigonemes.** On the basis of arrangement of mastigonemes tinsel flagella may be (i) **pantonematic** having two opposite rows of mastigonemes (Fig 2.6 D) (ii) **pantocronematic** is having a terminal fibril (Fig 2.6 C) and (iii) **stichonematic** flagellum in this mastigonemes develop only on one side of flagellum (Fig.2.6 D).

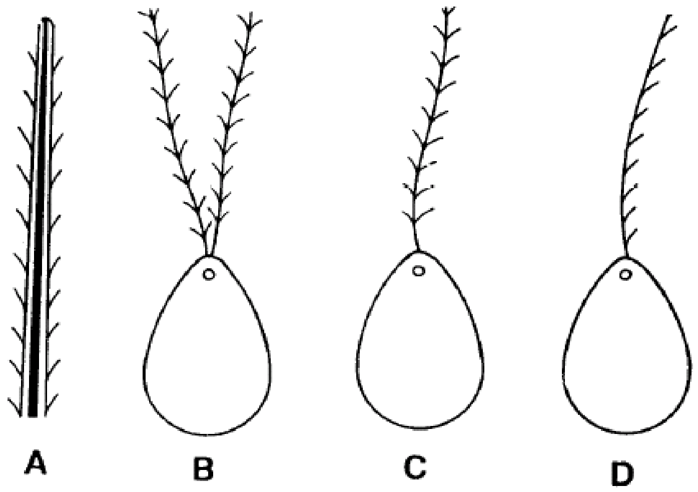


Fig.2.6: A- Pleuronematic (Tinsel), B – Pantonematic Flagella, C – Pantocronematic Flagella & D- Stichonematic Flagella

If the flagella of a cell are similar it is known as **isoknot** and when dissimilar, it is called **heteroknot.**

The size, number and arrangement of flagella are characteristic of specific class of algae or genera.

The motile stages of Chlorophyceae possess two or four anteriorly inserted whiplash flagella of equal length while the members of Phaeophyceae and Xanthophyceae have one whiplash and one tinsel flagellum of unequal length.

2.3.13 Reserve food material

As we know that the algae are the autotrophic organisms which are capable of synthesizing their food by the process of photosynthesis. The food synthesized during photosynthesis is stored in different forms in various classes of algae which is known as **stored food or reserve food material** which depends on the nature of pigmentation present in that particular class. Reserve food in green algae is starch, in Cyanophyceae it is cyanophycean starch, in Rhodophyceae it is floridean starch, while in Phaeophyceae it is mannitol and laminarian starch.

2.3.14 Pigmentation in algae

The colour of thallus in algae is due to presence of pigments. Each pigment has its own characteristics colour. Each algal division has its own particular combination of pigments and a characteristic colour. In all there are four different kind of pigments found in the Algae. These are chlorophylls, xanthophylls, carotenes and phycobilins. Usually the algal pigments are located in plastids. Different forms of plastids are present in algae. They may be cup shaped, in the form of parietal plate, lens- shaped, disc or network like or as an axial band, or star shaped (stellate) or oval shaped, a lobed disc or in the form of a parietal ring. The Cyanophyta lacks plastids and the pigments are located in the lamellae.

1-The chlorophylls

There are five known chlorophylls, namely, chlorophyll-a-b-c-d and –e. Of these chlorophyll a occurs in all classes of algae and the chemical formula of chlorophyll a is $C_{55}H_{72}O_5N_4Mg$.

Chlorophyll a and b are found in Chlorophyta, Euglenophyta and Charophyta. Chlorophyll-c occurs in Bacillariophyta, Pyrrophyta and Phaeophyta. Chlorophyll-d occurs only in red algae, while Chlorophyll-e is found in Xanthophyta. The plastids containing both chlorophyll a and b are called the Chloroplasts and those which lack Chlorophyll b and have carotenoids in excess over the chlorophyll are usually called chromatophores. Chlorophylls are fat soluble but insoluble in water. They absorb blue and red rays and are important photosynthetic pigments.

2-The carotenoids (Carotenes + Xanthophylls)
It is a group of yellow, orange, red and brown pigments. About 60 different carotenoids have been reported in plants. They are placed under two categories, the orange yellow **carotenes** and yellow or brown **xanthophylls** or carotenols. The carotenoids are protective pigments functioning as screens to light. They absorb blue and green light waves.

(a) Carotenes – The Carotenes are linear unsaturated hydrocarbons represented by a chemical formula $C_{40}H_{56}$. There are five carotenes so far known, namely Carotenes-a- B,-e,-Y and lycopene. Carotenes are fats soluble pigments. They are insoluble in aqueous solution but are soluble in lipid solvents such as ethyl alcohol, chloroform and carbon disulphide and absorb blue and green light waves.
(b) Xanthophylls- They are yellow or brown pigments represented by the molecular formula $C_{40}H_{56}O_2$. They are closely related to the carotenes but contain oxygen in addition to carbon and hydrogen. Both xanthophylls are insoluble in water but are soluble in chloroform. Common xanthophylls are Zeaxanthin, Astaxanthin, lycopene, Diatoxanthin, Oscilloxanthin, Fucoxanthin etc.
Fucoxanthin is characteristic pigment of the Phaeophyta imparting distinctive brown or olive coloration to the thalli.

3-The Phycobilins
It is another group of pigments comprising the tetrapyrrolic compounds joined to the globulin proteins. So far seven phycobilin pigments both blue and red have been enlisted. They are pycoerythrin r,- c,- x,- b- and phycocyanin-r and -c-. Phycobilin are water soluble pigment found in red and blue green algae. Of the seven phycobilins, r-phycoerythrin and r-phycocyanin are common, the former absorb blue, green and sometime yellow rays whereas the latter absorb green.

Chlorophyll-a is of prime importance in photosynthesis. The accessory pigments function only indirectly. The wavelength of light which is not absorbed by chlorophyll is absorbed by Phycocyanin and Phycoerythrin. The light energy trapped by the latter two pigments is then transferred to chlorophyll–a which utilize it in photosynthesis.

2.4 ECONOMIC IMPORTANCE OF ALGAE

Some most useful aspects of algae are mentioned below:
1-Algae as a Food for Man: From ancient times large numbers of green, brown and red algae are used as source of food by human beings. They are rich in carbohydrates, proteins,

vitamins and minerals. Many kind of seaweed are edible and rich in vitamins and iodine. *Porphyra* has 25-30% protein, vitamin B and C, minerals like iodine. *Porphyra* is considered to be a tasteful dish in England and is used in preparation of soup in Japan. A Japanese delicacy kombu is eaten in Japan which is prepared from the stipes of *Laminaria*. *Ulva* in Europe is called sea lettuce and it is used as food. In Scotland *Ulva lactuca* was used in preparation of salad and soups. The *Chlorella* is high in protein and lipid contents, therefore used as substitute food by Astronauts and Cosmonauts in space. In India a few species of *Oedogonium* and *Spirogyra* are used as food in South India. Iodine is manufactured from *Laminaria*. Algae are also used to decorate cakes, pastries, sandwiches in Japan. *Rhodymenia* which is popularly known as dillis in Ireland, Dulse in Scottland, and Sol in Iceland is in great demand as a food.

2-Algae as Fodder: Algae are nutritious, high in protein and a low cost food option for animals. Kelps (Brown algae) are used as fodder for cattle and chopped for sheep and chickens in Great Britain, France etc. *Rhodymenia* is used for cattle food in Norway and France. The diets of dairy cows and pigs can be supplemented with algal food. In China *Sargassum* is used as fodder. Adding algae to the diet of cows resulted in a natural breakdown of unsaturated fatty acids and a higher concentration of these beneficial compounds in milk and meat. The milk yielding capacity and number of eggs of the poultry increased by using kelp.

Fodder for aquatic animals: Algae form the base of the aquatic food chains that produce the food resources that fish are adapted to consume. According to Chacko (1970), "*Oscillatoria* is the most favoured blue-green alga consumed by 56 species of fishes. Others in order of preference are *Spirulina, Anabaena, Microcystis, Lyngbya and Merismopedia*". Certain types of algae are used in aquarium, fisheries etc. Snails, Tadpoles of frog and crabs etc also feed on algae. Micro algae are a natural component of the diet of many larval fishes. Diatoms form a permanent food of many aquatic animals along with some fishes.

3-Algae as Medicine: Algae have been used for centuries, as a remedy to prevent or cure various diseases. Researchers found that algae are beneficial for human health. A few algae yield antibiotis. Antibiotic chlorellin is obtained from green alga *Chlorella*, which inhibit the growth of certain bacteria. Chlorellin is effective against a number of Pathogenic bacteria. An antibiotic is obtained from a diatom *Nitzschia palea* which is effective against *Escherichia coli* due to high iodine contents. Many seaweeds are used in manufacture of various goiter medicines because of the high percentage of iodine content in them. Seaweeds have beneficial effect on thyroid glands, gall bladders, kidneys, uterus and pancreas. Kelpeck is prepared from kelps which is useful in the treatment of Goiter and other glandular troubles. An effective and important algal product is Agar-Agar which is used in the manufacture of ointments and tablets. Certain species of *Polysiphonia* produce anti bacterial substances which are effective against both gram-positive and gram-negative bacteria. Sea weed consumers are immune to hay fever. *Chara* and *Nitella* are used as mosquito repellents. *Chara* is useful in the destruction of mosquito larvae. In Japan *Spirogyra* is used in the manufacture of lens paper.

4-Algae in Nitrogen Fixation: It has been observed that species of blue -green algae are able to fix atmospheric nitrogen in the soil. Species of *Anabena, Nostoc, Calothrix, Scytonema, Aulosira, Stigonema, Tolypothrix, Gleotrichia* etc are the common nitrogen fixing blue green algae. It has been found that about 60 species belongs to blue green algae are capable of nitrogen fixation. Increase in amount of nitrogen makes the soil fertile. Blue green algae are used for nitrogen fixation in rice fields. Many countries like Japan, China, Philippines, Thailand and India have practiced the use of blue green in rice cultivation.

5-Algae in reclamation of Soil: The blue-green algae can also be used in the reclamation of barren alkaline soils. It has been observed that some blue-green algae form a thick stratum on the surface of the saline usar soils during the rainy season. These algae can be of used in the reclamation of the 'usar' lands. During the rainy season various species of *Scytonema, Nostoc, Anabaena, Aulosira* etc grow in plenty. Gradually they decrease the alkalinity of soil and increase the nitrogen, phosphorus and organic content in the soil thus converts it into a fertile land after sometime. **Binding of Soil Particles:** Algae play an important role as binding agent on the surface of the soil. The sea weeds have the properties of soil binding. The concentrated extract of seaweeds are sold as liquid fertilizer and added to lands.

6-Algae as Fertilizers: Since ancient times, most of the coastal countries of the world used the sea weeds as fertilizers. Sea weeds are rich in Potassium chloride (KCl), Phosphorous, calcium, some trace elements and growth substances. *Oscillatoria, Spirulina, Scytonema* etc are used in rice fields. To overcome calcium deficiency *Chara* is used in the fields. *Fucus* is used as common manure in Ireland in the cultivation of tuber crops. Scientists have been successful in preparing a liquid fertilizer from a brown seaweed *Sargassum* which contains micronutrients required for plants. The large brown and red algae are used as organic fertilizers due to the presence of potassium. Green algae also increase the soil fertility.

7-Algae in Industry: Algae yield certain chemical products which are extensively used in various industries. The four major products derived commercially from algae are- Diatomite, agar, carrageenin and alginates.

Diatomite: Diatomite is a soft, powdery, highly porous, friable light coloured sedimentary rock formed by the accumulation of the amorphous silica remains of dead diatoms in marine sediments. The fossil remains consist of a pair of symmetrical shells or frustules. Diatomite, also known as diatomaceous earth, has various applications. It is used in the preparation of Dynamite in ancient time. Alfred Nobel used the properties of diatomaceous earth in the manufacture of dynamite as an absorbent for nitroglycerin. Due to its highly absorbent and fire proof properties it is used in filters in brewing industries, sugar refineries etc. In paints, diatomite alters glass and sheen and in plastic it works as an antiblocking agent. It is used as insulator in furnaces and pipes. Diatomite has been used in toothpaste, metal polishes and in some facial scrubs. Due to its abrasive and physico-sorptive properties it is used as an insecticide.

Kelps are a rich source of soda, iodine, potash and aliginic acid. Japan produces about 100 tons of iodine per year from kelps. Potash and soda from seaweeds are used in the manufacture of alum, soap, glassware etc. In Japan, Funori is a type of glue obtained from red alga *Gleopeltis furcata*. It is used for sizing paper and cloth. It is also used as an adhesive.

Agar-agar: Agar-agar is dried, non-nitrogenous, jelly like substance extracted from different species of red algae. Japan produces the largest quantity of agar and exports it to other countries. Agar-Agar is used as a culture medium in laboratories for culturing microorganisms because of its ability to afford good range of temperature for culturing. Its melting point is between 90 and 100^0 F. At lower temperature it changes into a solid. Agar is employed as thickening material in the preparation of ice-cream, jellies, deserts, melted milk, candies, pasteries, sauces, soups etc. It is also used for making moulds for artificial leg, artificial silk and leather. Agar is used as a lubricant for photographic films. In the medicine, agar is used as a laxative.

Alginates: Alginates or alginic acid was discovered in sea weeds and isolated from *Laminaria*. Alginates are the salts of alginic acid present in the cell wall of Phaeophyceae. It is insoluble in water and hard when dry but can absorb water 200-300 times its weight. They are usually extracted from the middle lamella and primary walls of the brown and red algae. Alginates are used in the preparation of flame-proof fabrics, water proofing concrete, production of non-inflammable wrapping film, in surgical dressing, ice-creams etc. Sodium alginate is used in sizing material for water proof articles dyes etc.

Carragenin: Carragenin, usually extracted from cell wall of red algae like *Chondrus crispus* and *Gigartina*. It is a polysaccharide esterfied with sulphate. Carragenin is extracted by boiling algae with 100 parts of water. When Carragenin dissolves in water, it is mixed with active charcoal and filtered. At last the gel obtained is carragenin. It is used as emulsifier in pharmaceutical industry. Carragenin is also used as a remedy for cough. It is used in stabilizing and gelling foods, leather industry, brewing industries and textile manufacture.

Algae as fertilizers: Blue-green algae treated as bio-fertilizers from ancient time. A bio-fertilizer is a substance which contains microorganisms which restore the soils natural nutrient cycle and build soil organic matter. Cynophyaceae (Blue-green algae) act as bio-fertilizers. They have the capacity to accumulate mineral such as sulphur, calcium, potassium, zinc, magnesium, copper, iodine, boron, lead, nickel, antimony, arsenic, manganese, cobalt, molybdenum. Sea weeds are used as fertilizers in many countries due to the presence of Potassium chloride. The red algae and larger brown algae are rich in potassium. They are also used as organic fertilizers. Concentrated extract of sea weeds is sold as liquid fertilizers.

Algae as a source of biofuel: Alga fuel or alga biofuel may provide an alternative to fossil fuel. Algae based biofuels is a new energy source. Algal biofuels use algae as a source of natural oils. The oils can be extracted from the harvest and then refined into biodiesel, gasoline, diesel or even jet fuels. Algal based biofuels is non-toxic, biodegradable and contains no sulphur. It can reduce CO_2 emissions. Scientists are exploring more possibilities of using algae to make gasoline, diesel and other fuels.

2.5 GENERAL CHARACTERSTICS OF BRYOPHYTES

2.5.1 Habit

The plant body of bryophyte is broadly divided into two types. It may be a simple thallus (thallose) or a leafy shoot (foliose). Sometimes partly thallose or partly foliose forms are also found.

Thallose Forms: The gametophyte is a thallus. The thalloid forms are not differentiated into stem and leaves. The thallus is usually flat, green, prostrate, dorsi-ventral and dichotomously branched (Fig. 2.7). It has a distinct midrib (*Riccia* and *Marchantia*) or midrib may be absent

(*Anthoceros*). Thallus is generally fixed on the soil by means of rhizoids and in many cases possesses scales on the ventral surface.

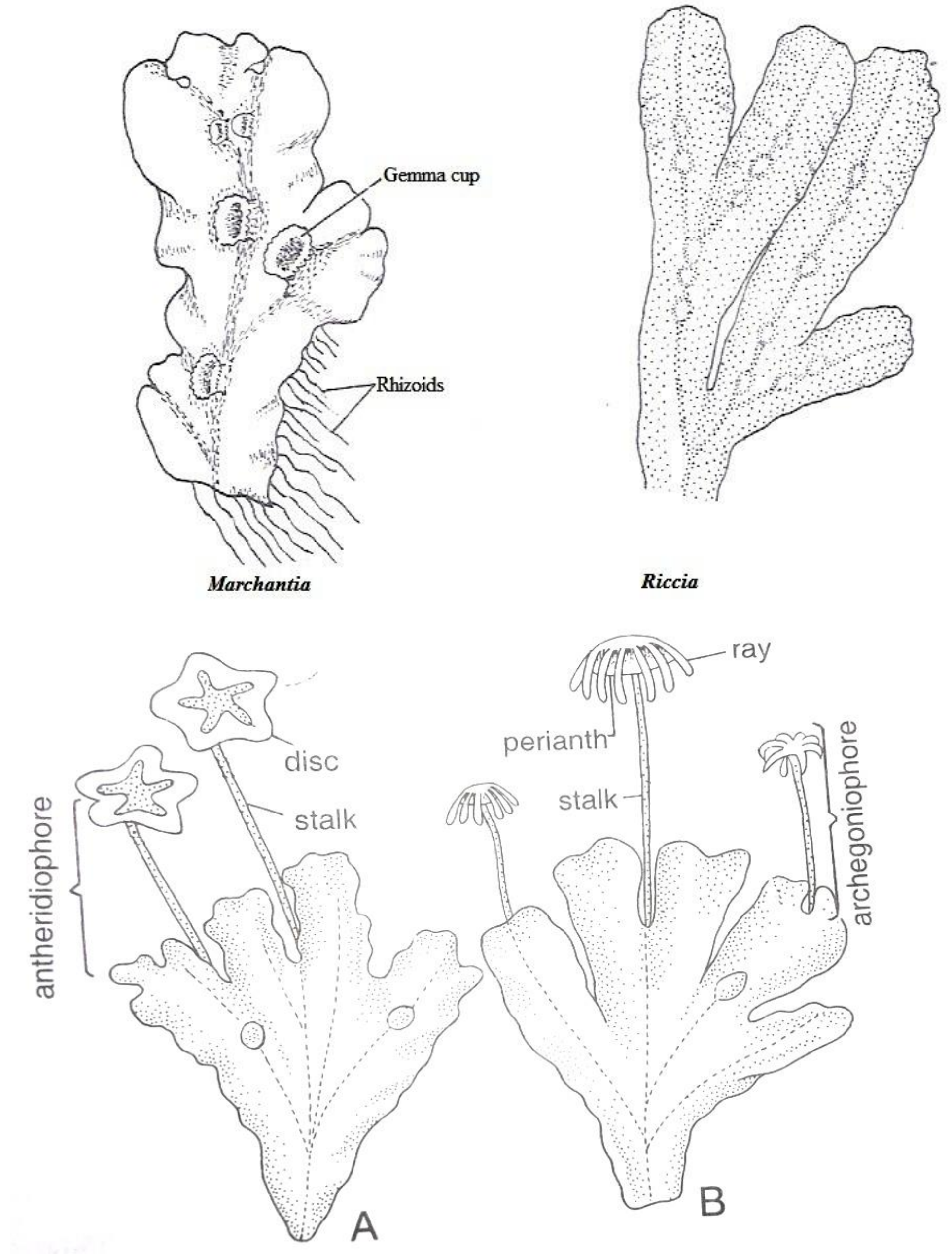


Fig. 2.7 Thalloid forms

Leafy Forms: The gametophyte of leafy liverworts has more or less prostrate leafy axis and have three rows of leaves; two rows of dorsal leaves which are placed laterally, one on each side of the stem and a third ventral row of smaller leaves, which are present on the underside of the stem (*Porella*). The leaves are always without a midrib (Fig 2.8 A). The rhizoids are not septate. The protonema is small and short- lived.

In mosses, gametophytic plant body is a leafy shoot consisting of main axis (stem), phylloids (leaves) and rhizoids (Fig. 2.8 B, C). The leaves are small, simple sessile and are spirally arranged on the stem in three vertical rows. The leaves generally possess a midrib of variable size. Branching is lateral (*Funaria* and *Polytrichum)* and pinnate type. Rhizoids are branched and transversely septate. Protonema a juvenile stage in mosses is well developed, filamentous and branched. Sometimes thalloid protonema is also found.

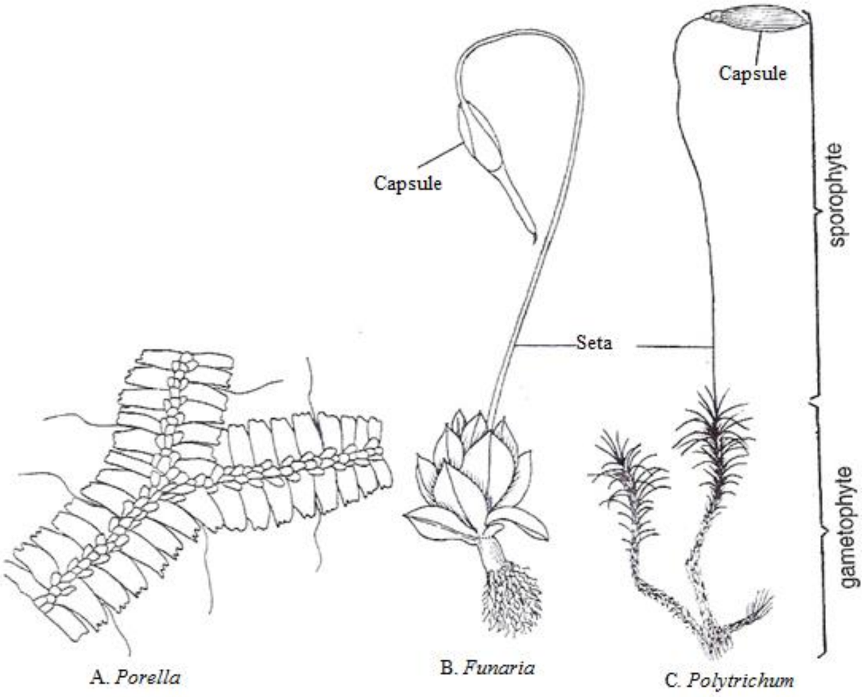


Fig. 2.8 Leafy forms

2.5.2 Distribution

Bryophytes tend to show wider distributions than flowering plants. Many families are found throughout the world. Several genera, like *Polytrichum, Grimmia, Bryum* and *Brachythecium* among mosses; *Plagiochila*, *Lophpcolea*, *Radula* and *Frullania* among liverworts are worldwide in distribution. Some of the species are known as international weed species as they are cosmopolitan in distribution, for example, *Funaria hygrometrica, Tortula muralis* etc.

Herzog (1926) indicated certain patterns of distribution that was repeated again and again. Therefore, groups of families and genera that showed **circumboreal, Mediterranean, Pan tropical, bipolar** and other kinds of distribution can be observed. Endemism, among bryophytes is of two main kinds. First, there are forms which are evolved recently and lacked the time to achieve wider distribution. Second, those ancient species which vanished from their stations elsewhere; and now they have become restricted to a single country. Some of them evolved far back in time but because of geographical barriers remained **endemic.**

In Indian context, Pande (1958) and Kachroo (1969) divided the Indian subcontinent into six bryo-geographical units each one with distinctive vegetation (See Map).

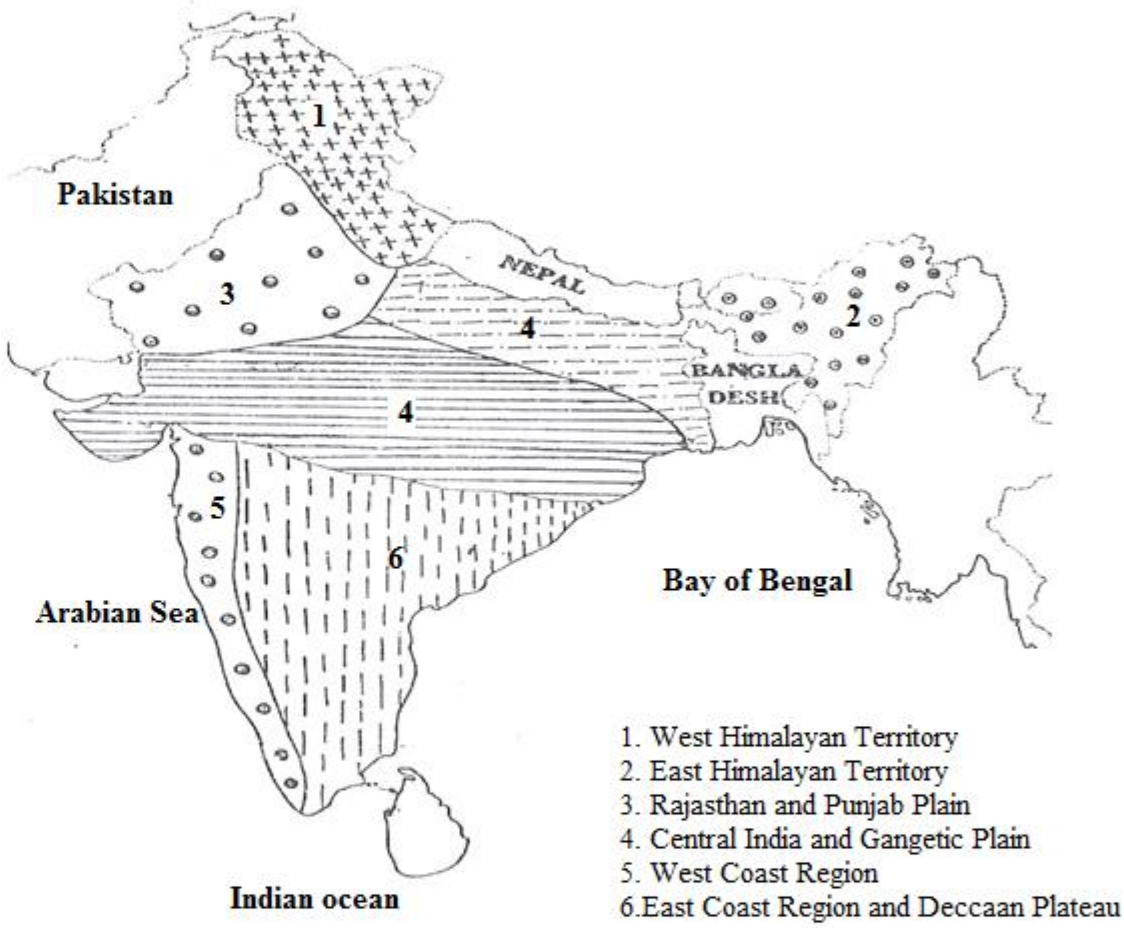


Fig. 2.9 Map of India showing Bryogeographical units

1. **The Western Himalayan Territory:** It extends from the western boundary of Nepal to Kashmir. In this area rain fall is less. The most luxuriant vegetation occurs between altitudes 6000-8000 ft. The vegetation is characterized by some endemic genera and arctic species such as *Sauteria alpina* and *S. spongiosa*. Some temperate or cosmopolitan elements common to Europe are also represented. An interesting plant is the genus *Delavayella* with restricted distribution in Almora, and Darjeeling.
2. **Eastern Himalayan Territory:** It comprises the eastern part of mountains of Indian Territory that separates the India proper from Burma and China and includes a vast area of Assam: The rain fall in this area is fairly heavy. Some plants confined entirely to this territory in India and with restricted distribution in other parts of the world, present interesting distribution patterns. *Conocephalum supradecompositum* is known from subtropical regions of Japan,the province of Shensi in China and from Darjeeling, *Monoselenium tenerum* is known from China, Japan and Assam; *Jackielia* Schiffn. has its 5 species distributed in Japan, Java, Ceylon, Sumatra, Singapore, Tahiti and Caroline Islands and among these *J. javanica* var. *carvifolia* Schiffn. is known from Darjeeling; *Schiffneria* St., represented by a species in Japan (*S. viridis* St.), another in Batjan (*S. hyalina* St.) is also represented in Indian flora by *S. levieri* Schiffn. from Darjeeling and *Megaceros stahlii* is distributed only in Java and Darjeeling.

3. **The Punjab and the west Rajasthan plains:** This area with very low and inconsistent precipitation is not well-suited for hepatic growth. Only some xeromorphic forms such as species of *Asterella, Plagiochasma, Riccia* and *Targionia* grow in favourable habitats.
4. **Central India and the Gangetic plain:** In this part of the country, although the rain fall is not very heavy (average 70-80 inches) the hepatic vegetation is comparatively more luxuriant. About 40 species are known, of which 26 are common to the western Himalayas, 18 to the eastern Himalayas and 24 to South India. The area is a meeting ground for the hepatics of northern and southern parts of India. Some of the interesting plants known from this zone are *Anthoceros crispulus*, *Riccia curtisii* and *Riella affinis*.
5. **The west Coast region:** This region lies between the crests of the Western Ghats and the Arabian Sea. Places such as Augumbe, Kunduremukh and Dodabetta, with heavy rainfall, support luxuriant hepatic vegetation and particularly Augumbe (rainfall ca. 35inches) abounds in a number of epiphyllous liverworts. Several of these, viz., *Cololejeunea, Diplasiolejeunea, Leptocolea, Microlejeumea, Rectolejeunea,* etc. strongly resemble their African allies and also to that of Mouflong forest in Assam and Sikkim Himalayas. *Leptocolea* has an interesting distribution pattern. *L. himalayensis*, described from the western Himalayas has been reported from South Africa and probably also occurs in South India and the eastern Himalayas and *L. marginata* and *L. ocellata* known from America and Japan occur also in South India (Chopra, 1938).
6. **The East Coast region and Deccan plateau:** This zone consists of the Eastern Ghats, the Nilgiris and the Deccan plateau. It has about 31 species of liverworts common to Indo-Malayan countries including Java, Formosa, Sumatra, Philippines, Luzon, Borneo, Siam, Caroline Islands, Nicobar, etc. The Deccan plateau has no distinctive flora and shows plants common to the western and Eastern Ghats and is a meeting ground for the vegetation of these two areas.

2.5.3 General Characters of Bryophytes

The term Bryophyta was introduced by Braun (1864), wherein he included Algae, Fungi, Lichens and Mosses. Schimper (1879) formed the division Bryophyta. The meaning of this word is moss like plants (Gr. Bryon = Moss; Phyton = plant).

Bryophytes as Amphibians of Plant Kingdom

The bryophytes occupy the position intermediate between the green Thallophyta (Algae) and the vascular cryptogams (Pteridophyta). The plants that grow in water are called aquatics and others are terrestrial. In Aquatics you must have studied algae. In land plants you will study the seed bearing plants (spermatophytes).

Between the land and water, a transitional zone is present, where plants can grow on both the habitats (water and land). These plants are known as bryophytes and they have successfully adapted to land as well as water. But, these may be regarded as incompletely adapted to land conditions, because all of them require water for the act of fertilization. Most of them require sufficient moisture for vigorous vegetative growth and they are unable to grow actively during dry periods. On account of their complete dependence on external water for completing their life cycle, the bryophytes are known as the amphibians of the plant kingdom.

2.5.4 Salient Features in the Life Cycle of Bryophytes

The gametophyte is the conspicuous and dominant phase of the life cycle as compared with the sporophytic generation. The gametophyte is small, highly developed with tissue differentitation and is an independent plant.

1. The gametophyte plant body is rootless either a simple flattened thallus or a definite rootless leafy shoot (leafy form; Fig. 9.1 and 9.2).
2. The thalloid plant body is not differentiated into root, stem and leaves. It grows prostrate on the ground and is attached by branched or unbranched unicellular or multi cellular hair like structure, the rhizoids (Fig. 2.10). In leafy forms that is, in mosses the plant body is erect. It consists of central axis which bears leaf like expansions.
3. Like the thallophytes, the dominant phase of the life cycle of bryophytes is the gametophyte. It is independent and related to sexual reproduction.
4. In general, Bryophytes does not possess vascular tissues (xylem and phloem) in their sporophytes and gametophytes, which is present in fern and other higher plants, and therefore also called as Atracheata by Tippo (1942).

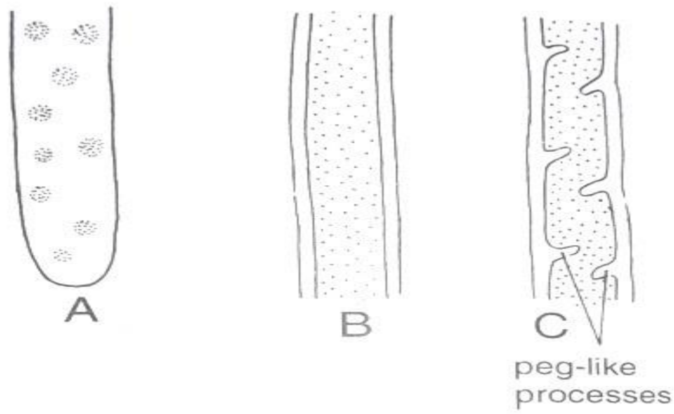


Fig. 2.10 Rhizoids; A. Tuberculate rhizoid in surface view, B&C Smooth walled rhizoid and tuberculate rhizoid as under microscope

2.5.5 Similarities between the Bryophyta and Algae

1. Presence of thalloid plant body is a feature of both Bryophyta and Algae.
2. In both groups, the dominant phase of the life cycle is gametophyte.
3. In both groups, plants are autotrophic in nature.
4. In both groups, chloroplast contains chlorophyll a, chlorophyll b, alpha and beta carotene, lutein, violaxanthin and xeoxanthin.
5. In Chlorophyceae (green algae) and Anthocerotales plastids with pyrenoids are present.
6. In both groups starch is the reserved food material
7. In both groups, vascular tissue is absent and Cellulose is the chief constituent of cell wall.
8. In both groups, motile and flagellate antherozoids with whiplash type of flagella are present.
9. A filamentous protonema, formed in the juvenile stage of mosses, resembles with algal filaments in structure.

2.5.6 Differences between the Bryophyta and Algae

1. Bryophytes are generally terrestrial growing on shady and moist habitats, whereas most of the algae are aquatic.
2. In bryophytes plant body is multicellular thalloid or leafy in form differentiated into rhizoids, axis and lateral appendages, while in Algae plant body is unicellular, multicellular, filamentous or pseudo parechymatous.
3. In Bryophytes, sexual reproduction is oogamous type while in algae it is isogamous, anisogamous and oogamous type.
4. In Bryophytes, female sex organ is Archegonium while in algae it is oogonium.
5. In Bryophytes, sex organ are covered by a sterile jacket while in algae it is not covered by a sterile jacket.
6. In Bryophytes, zygote remained enclosed in the archegonium while in algae zygote is liberated from the plant.
7. In Bryophytes, zygote develops into embryo while in algae zygote never develops into embryo. Hence embryo stage is present in Bryophytes and absent in algae.
8. In Bryophytes, sporophyte is dependent on gametophyte while in algae it is independent of gametophyte.
9. In Bryophytes, sporophyte is differentiated into foot seta and capsule while in algae no such differentiation is seen in sporophyte.
10. In Bryophytes, mitospores are absent while in algae mitospores are usually present
11. In Bryophytes, alternation of generation is heteromorphic while in algae alternation of generation is isomorphic type.

2.5.7 Similarities between the Bryophyta and Pteridophyta

1. Simple leafless and rootless sporophytes of certain primitive pteridophyte (members of Psilophytales) can be compared with the sporophytes of bryophytes.
2. In both groups plants are archegoniate, and the structure of archegonium is similar.
3. Antheridium in both the groups is surrounded by a sterile jacket.
4. In both the groups, antherozoids are flagellate.
5. In both the groups, water is necessary for fertilization.
6. In both the groups, zygote develops into embryo.
7. The terminal sporangia with columella of Psilophytales are similar to moss capsules
8. Both groups are characterized by the presence of heteromorphic alternation of generation.

2.5.8 Differences between Bryophytes and Pteridophytes

1. In bryophytes, dominant phase of life cycle is gametophyte whereas in Pteridophyta, sporophyte is the dominant phase in the life cycle.
2. In bryophytes, vascular tissue is absent whereas in Pteridophyta, vascular tissue is present.
3. In bryophytes sporophyte is completely dependent upon the gametophyte whereas in Pteridophyta, sporophyte is autotrophic and independent.

2.6 ECONOMIC IMPORTANCE OF BRYOPHYTES

Bryophytes are the simplest and primitive land plants which are one of the first colonizers of the terrestrial habitat. Taxonomically, these plants are placed between algae and Pteridophyta. They are generally represented by about 21000 species (Schofield, 1985) with a worldwide distribution. As a group, bryophyte is divided into three classes:, Hepaticapsida (liverworts, 6000 species) , Anthocerotopsida (hornworts, 300 species) and. Bryopsida, (mosses,14000 species). Owing to their potential to live on a variety of habitats, they are exposed to differential degree of biotic and environmental hazards. To cope up with these adverse conditions, numerous secondary metabolites of several types are synthesized in their tissues as a defense system (Herout, 1990). A lack of commercial value, small size, and inconspicuous place in the ecosystem has made the bryophytes to be of no use to general public. But still bryophytes have been useful in many ways to the mankind.

2.6.1. Peat Formation: ***Sphagnum*** and other mosses are the chief constituent of Peat. Peat is the partially decomposed plant material in the bogs which is gradually compressed and carbonized under pressure of the overlapping deposits of decaying material. This is hardened by the weight of fresh deposits in due course of time and attains considerable thickness .The compact, partially decomposed and carbonized dead plant deposits are called peat, and used in various ways.

2.6.2. Cleaning Agent: Bryophytes have been used for cleaning up toxic wastes. At some places sewage waste has been diverted through peat land for cleaning as well as to clean up factory effluents containing acid and toxic heavy metal discharge, detergents, and dyes. Microorganisms have also been removed by ***Sphagnum*** perhaps due to the antibiotic properties of the peat.

2.6.3. In Horticulture: In horticulture practices bryophytes have been used traditionally as soil additives for, ground cover, as wll as for dwarf plants, greenhouse crops, potted ornamental plants, and even for seedling beds. ***Sphagnum*** is used in making small poles to support climbing plants and moss-filled wreaths. Other horticultural uses of bryophytes include making baskets and covering flower pots and containers for floral arrangements. Wet ***Sphagnum*** is used typically for shipping live plants.

2.6.4. Mycorrhizal Association: ***Cryptothallus mirabilis*** a colourless bryophyte that lives at the expense of mycorrhizal fungi It is observed that the association of bacteria with moss is necessary before the bud induction. The association of bryophytes with bacteria is attributed to the capability of bryophytes to retain moisture.

2.6.5. As Medicine: ***Sphagnum*** was used as a surgical dressing during world war I. ***Sphagnum*** is superior to cotton dressings in a number of ways. It absorbs three to four times liquid and three times faster, necessitating less frequent change. It is also cooler, softer less irritating and retards bacterial growth.

Bryophytes are traditionally used in North America, Europe, China, and India as herbal medicine to treat illness of cardiovascular system, bronchitis, skin diseases, burns, boils bruises and external wounds.

About 30-40 species of bryophytes are used as herbal medicine. Chinese people used ***Fissidens*** sp. as an antibacterial agent for swollen throats and other symptoms of arterial infections. ***Marchantia polymorpha*** is used to treat liver ailments like jaundice and externally to reduce inflammation. The Chinese also use ***Polytrichum commune*** as a detergent diuretic, laxative and hemostatic agent.

In India, people of Kumaun Himalaya used ***Marchantia polymarpha*** and ***M.palmata*** to cure boils, abscesses and to reduce pus formation, while paste of ***Riccia*** sp. is applied on the ring worm disease of skin. Simlarily ***Plagiochasma appendiculatum*** is used for treating skin disease by Gaddi tribe in Kangra Valley.

2.6.6. Anti-tumor Properties: The extracts of ***Polytrichum juniperinum*** had anticancerous activity against Sarcoma 37 in mice. Several compounds, like, Marchantin from ***Marchantia palacea, M. plymorpha,*** and ***M. tosana,*** show cytotoxic activity.

Medicinal uses of some bryophytes

Species	Physiological activities and effects
Concephalum conicum	Antimicrobial, antifungal, antipyretic, antidotal activity, for cuts, burns, fractures, poisonous snake bites, gallstones.
Marchantia polymorpha	Antipyretic, Antiseptic, antidotal, diuretic activity, for cuts burns, poisonous snake bites, open wounds.
Bryum argenteum	Antidotal, antipyretic, antithinitic, for bacteriosis
Ditrichum palladium	For convulsions, convulsions of infants.
Leptodictyum riparium	Antipyretic, uropathy.
Mnium cuspidatum	For haemostasis, external wounds, epilepsia.
Rhodobryum giganteum	Antipyretic, diuretic, cuts, antihypertension, for sedative cardiotherapy, expansion of blood vessel of heart.

2.6.7. Production of useful compounds: Ther are about 25 monoterpenes, 172 sesquiterpenes, 44 diterpenoids, 33 steroids and several other compounds have been reported from liverworts. Recent studies indicate that most of the hepaticopsids contain mainly lipophilic mono sesqui-diterpenoids, aromatic compounds and acetogenins which constitute the oil bodies. The biological activities of bryophytes are mainly due to the presence of these compounds.

2.6.8. Bedding, stuffing and caulking: In ancient times (A.D 90 to 120) people covered the floors of some of the buildings with thick layers of fern straw and mosses. Eighty five per cent mosses belonged to two species ***Hylocomium splendens*** and ***Rhytidiadelphus squarrosus***. Ancient man also packed mosses between the wall timbers in their house. A very important use of moss was as caulking material between the planks of boats built by both Bronze Age and Iron Age man.

2.6.9. Moss Gardens: In Japan, mosses are used in developing gardens instead of grass to prepare lawns. Moss gardens are often associated with Buddhist temples the most famous of which is Kyoto's Kokedera which is also called as mosses temple" ***Pogonatum*** and ***Polytrichum*** species are among the most-often used mosses for gardens. There are some other species also that are used in moss gardens which grow as cushions, creating landscape resembling miniature hills.

2.6.10. Fuel: In Canada there appears to be more energy in native peat deposits than in forests and natural gas reserves. Mosses are important sources of fuel in northern Europe, especially in Finland, Germany, Ireland, Poland, Russia, and Sweden. 25% of the fuel in Ireland is moss-based.

2.6.11. Construction: In countries where bryophytes are common, they have been important constituent in construction of houses, furnishings, boats, and other items and are still used today, especially in construction of log cabins.

2.6.12. Household Use: Mosses are widely used for decoration in store windows and displays, Christmas tree and toy train yards, floral arrangements, and Christmas ornaments.

2.6.13. Clothing: In Germany, ***Sphagnum*** is used to line hiking boots where it absorbs moisture and odor. Women in the villages of Kumaun, India, stuff mosses into cloth sacks to make head cushions (sirona) that also absorb leaking water as they carry water vessels.

2.6.14. As food source: The Chinese consider mosses to be a famine food.

2.6.15. Flavouring: Mosses have been used for flavouring. ***Sphagnum*** contributes to flavour the Scotch whisky. In a drink of wine, ***Marchantia polymorpha*** soaks up the wine and makes a tasty, crunchy treat drink.

2.6.16. Ecological Uses of Bryophytes

Both liverworts and mosses are often good indicators of environmental conditions. The terrestrial bryophytes and other plants are used to characterize forest types.

a. **Soil Conditioning:** Mosses are often used in conditioning of soil. Coarse textured mosses increase water-storage capacity, whereas fine-textured mosses provide air spaces Mosses accumulate potassium, magnesium, and calcium from rainfall. These trapped nutrients may then be released slowly to soil.

b. **Erosion control:** It was found that ***Barbula, Bryum,*** and ***Weissia*** were important pioneers on new road banks, helping to check soil erosion before the establishment of larger plants. In Japan, it was observed that ***Atrichum, Pogonatum, Pohlia, Trematodon***. ***Blasia,*** and ***Nardia*** play an important role in preventing erosion of river banks.

c. **Nitrogen Fixation:** Nitrogen is generally a limiting nutrient for plant growth. Bryophyte crusts, enriched with nitrogen fixing Cyanobacteria can contribute considerable soil nitrogen, particularly to dry range land soil. Some of these Cyanobacteria live symbiotically with ***Anthoceros*** thalli.

d. **In Pollution studies:** Bryophytes play a major role in monitoring changes in the Earth's atmosphere. In Finland, ***Hylocomium splendens*** was used as moss bags to monitor heavy metals around coal-fired plants.

e. **UV Radiation:** The moss ***Bryum argenteum*** is being used to monitor the thickness of the ozone layer over Antarctica (Hedenas 1991). There is, increased exposure to UV radiation with the decrease of ozone layer and UV radiation stimulate production of flavonoids in this species.

f. **Radioactivity Indicators:** Because of the ability of bryophytes to trap minerals without any harm to thalli, they are good indicators of accumulated radioactivity. Because of its cation exchange activity, Fischer *et al*. (1968) suggested that ***Sphagnum*** could be used to decontaminate water containing radioactive materials.

g. **Indicators:** Both liverworts and mosses are often good indicators of environmental conditions Copper mosses grow almost exclusively in areas high in copper, particularly when copper value is ranging from 30-770 ppm, Some of the copper mosses are ***Mielichhoferia elongata, M. mielichhoferi*** and ***Scopelophila* sp.** Bryophytes are also useful as monitors in aquatic habitats. The death of bryophytes is slow and the release of accumulated substances permits the bryophytes to retain their toxic load after death (Pakarinen 1977).

h. **SO_2 and Acid Rain:** It was t found that SO_2 could limit distribution, reproductive success, and capsule formation in mosses. ***Grimmia pulvinata*** was used as an indicator of SO_2 in England. .Acid rains due to SO_2 emissions, can actually improve conditions for ***Pleurozium schreberi*** in some Jack pine (*Pinus banksiana*) forests.

i. **Bog Succession:** Peat mosses on the banks of lakes and water bodies extend inwards and grow over the surface of water and form thick mats. This moss mat because of the moisture and humus forms a suitable substratum for the germination of seeds of various species and with time the mosses and herbaceous vegetation is replaced by higher plants.

j. **As Rock Builders:** Certain mosses growing in association with other plants bring about decomposition of bicarbonate ions and liberate carbon di oxide if the underlying rock is rich in calcium. This precipitates as calcium carbonate around the plants which gradually hardens. These deposits continue to grow and are used as building stones.

2.7 SUMMARY

Algae are the first chlorophyll bearing thalloid organisms which can synthesize their own food by the process of photosynthesis. They exhibit a great diversity in their thallus organization ranging from unicellular to parenchymatous. Flagella are present in all the classes of algae except Cyanophyceae and Rhodophyceae. Algae are cosmopolitan in nature and present almost every place where life is possible but predominantly they are aquatic. The plant body of algae is thalloid having no differentiation into root, leaf and stems. Sex organs are unicellular and if multicellular each cell is fertile. The cell structure of algal thalli is basically of two kinds prokaryotic and eukaryotic. The prokaryotic cell having incipient nucleus is present only in the class Cyanophyceae while all the other classes of algae exhibit eukaryotic cell structure having a well developed nucleus and all the membrane bounded cell organelle present in the cell. Algae are economically very significant as it provides food, medicine, fodder for animals. Algae also have many commercial and industrial uses, in addition to their ecological roles as oxygen producers and as the food base for aquatic animals. Another potential use is in the production of bio-fuels. Algae are indicators of ecosystem pollution.

The habit of the bryophyte plant is either thalloid or leafy in nature. In thalloid forms, there is no differentiation into leaf, stem and roots, while leafy forms are differentiated into leaf, stem and root like structures. Generally bryophytes are world- wide in distribution, but some of the genera or species show restricted distribution and may be endemic. In Indian context, the distribution of bryophytes can be studied by dividing the Indian sub continent into 6 bryogeographical units. Bryophytes are broadly classified into 3 classes viz. i. Hepaticopsida ii. Anthocerotopsida and iii. Bryopsida. Each class is further divided into a number of orders. Since ancient times, bryophytes are variously used. Bryophytes are little known for their economic importance. However , they are being used varioully now a days, for example, they are used in peat formation, medicinal use of species of ***Marchantia, Polytrichum*** etc, antibiotic activities against microorganisms, as fuel, food, packing material, in horticulture and moss gardens etc. Ecologically, these plants help in soil formation and conservation, as well as in development of vegetation cover, in succession, as a rock builder, seed bank, pollution indicator etc.

2.8 GLOSSORY

Agar-Agar- Gelatinous product of certain sea weeds, it is used as a base for bacterial culture media and as a food additive

Algal bloom- high concentrations or densities of algae.

Algin- the soluble sodium salt of alginic acid

Alginate- the salt form of alginic acid

Alginic acid- A viscous gum that is abundant in the cell walls of brown algae

Amphibians- Plants that is adapted to live in land and water both.

Antheridium- The male sex organ of the cryptogams.

Antidotal- That related to counteract the harmful effects.

Antipyretic-The drug that reduces fever

Aplanospore- Asexually produced non motile spore.

Archegonium- The female sex organs of bryophytes, containing the egg inside a cellular jacket.

Archesporium-The first cell generation of sporogenous tissue, or the cell or group of cells from which the spores of a sporangium are ultimately derived.

Autotrophic- Plant that can make their own food by the process of photosynthesis

Bacteriosis- Any infection by bacteria

Boreal- Pertaining to North

Calyptra-A covering developed from the venter of the archegonium in bryophytes, which surrounds the young sporophyte.

Capsule - The part of the sporogonium containing spores.

Cardiotherapy-Treatment of heart diseases

Caulking- A sealing material used to seal joints between heterogenous materials.

Chryophyceae- unicellular golden brown algae that inhabit fresh and salt water environments.

Circumboreal- The distribution pattern of organisms around the high latitudes of the northern hemisphere of boreal zone. .

Convulsions- An intense involuntary muscular contraction

Crusts- A solid hard layer on the surface

Cyanobacteria- Photosynthetic prokaryotic microorganisms (blue green algae)

Diatom- A unicellular alga encased in siliceous shell or frustules a member of the class Bacillariophyceae

Diatomaceous Earth- Siliceous deposits made up of the sedimentary buildup of diatom frustules

Dichotomous- The state of equal division of the growing point to form two equal branches.

Dinoflagellate- A single-celled organism found in fresh and marine waters.

Dioecious- Having unisexual male and female sexual reproductive organs borne on different thalli.

Diploid- Nuclei having double the number of chromosomes (2n).

Diploid generation- The sporophyte.

Diuretic-That increases the frequency of urination

Dorsiventral- An organ having distinct dorsal and ventral surfaces which show difference in colour.

Elaters- Hygroscopic structures helping to disperse spores.

Embryo- Young plant developed within the archegonium from zygote.

Endemic - Restriction of a species or a taxonomic group to a particular geographic region.

Endothecium- The inner layer of a young sporogonium in bryophytes.

Foliose- Having a leafy shoot.

Green Alga- A member of the Chlorophyaceae.

Habit- General form and aspect of a plant.

Habitat- A place or condition suitable for an organism to live in.

Haploid- Having a single set of unpaired or reduced number of chromosomes in each nucleus.

Heterogamy- In sexual reproduction when the two fusing gametes are morphologically different

Homosporous- Producing one kind of spores.

Hygrophilous- Plants which need a large amount of moisture for their growth.

Hypnospore- Thick walled spore, meant for perennation

Involucres- A protective envelope enclosing the reproductive organs.

Laminaria is a genus of 31 species of brown algae commonly called “Kelp”.

Mediterranean- A relatively small region, being restricted to Iberia and Mediterranean coast.

Oogamy- Fusion of motile sperm with non motile passive egg

Pan tropical- The distribution pattern of organisms that occur more or less throughout tropics.

Peristome - The ring of hygroscopic teeth round the mouth of mature capsule.

Pharmacology- The study of science of drugs.

Phycology- Study of algae

Pollution -Contamination of environment by harmful agents.

Prostrate -Trailing on the ground

Protonema-The early filamentous stage produced on germination of the spore in some bryophytes.

Rhizoids- Single or many celled hair like structures for the attachment of gametophyte in bryophytes and perform the function of roots

Sedative-A drug that have a soothing effect

Seta- The stalk of sporogonium in liverworts and mosses.

Sporogonium- The spore producing structure of bryophytes

Terrestrial- Plants living on ground.

Thallose- Having a form of a thallus.

Thallus- Plant body that is not differentiated into root leaf and stem
Wreaths- something intertwined or curled
Zooplankton- Microscopic animals that are suspended in the water reservoirs
Zoosore- Asexually produced motile spore

2.9 REFERENCES & SUGGESTED READINGS

- Asakawa, Y. (2007). Biologically active compounds from bryophytes.Pure Applied Chemistry 7: 22-29.
- B.P. Pande- College Botany. S. Chand publication.
- B.R. Vashistha revised by Sinha A.K. and V.P. Singh. 2010. Algae. S. Chand and Company LTD. Ram Nagar New Delhi 110055.
- Belkin M., Fitzgerald D.B. and Felix, M. D. (1952). Tumor damaging capacity of plant materials .II. Plants used as diuretics. J. Nat. Cancer Inst. 13:741-744.
- Bland, J. (1971). Forests of Lilliput. Prentice-Hall,Englewood Cliffs,N.J. 210 Pp.
- Chapman, D.J. and Chapman, V.J. 1961. Life histories in the algae.*Ann.Bot.*N.S.25:547-561
- Chopra, R.S. (1938). Notes on Indian Hepatics.I. South India. Proc .Indian Acad. Sci. 7B: 239-251.
- Crum, H. (1973). Mosses of great lakes forest. Contributions from the University of Michigan Herbarium. Vol.10. 404 Pp.
- Ding, H. (1982). Medicinal spore-bearing plants of China. 409 Pp. Shanghai.
- Dixton, P.S.1963. Terminology and algal life histories with particular references to the Rhodophyta. *Ann. Bot.*Lond.N.S.27: 353-355.
- Drew, K.M.1955.Life histories in the algae with special reference to the Chlorophyta , Phaeophyta and Rhodophyta. *Biot. Rev*., 30: 343-390.
- Fritch, F.E.1942 b II. The algal life cycle, *Ann Bot.* NS 6: 533-563
- Glime, J.M. and Saxena, D. (1991) Uses of Bryophytes.Pp.100. Today & Tomorrow's Printers & Publishers, New Delhi.
- H.C. Gangulee and A.K. Kar. College Botany. Vol II. New central book agency
- Herzog, Th. (1926). Geographie der Moose. Jena
- Hotson, J. W. (1918*). Sphagnum* as a surgical dressing. Science, N.S. 48: 203-208.
- Hotson, J. W. (1919). *Sphagnum* from bog to bandage. Puget Sound Biol.St.Bull. 2: 211-247.
- Hotson, J. W. (1921). *Sphagnum* as a surgical dressing in Germany during the world war. Bryologist 24: 74-78; 89-96.
- Howe, M.A. (1899). The Hepaticae and Anthocerotes of California, Mem, Torrey Bot. Club, 7:1-208.
- Kachroo, P. (1969). Hepaticae of India—A Taxonomic survey and census. I. Floristic and Taxonomic considerations.Kashmir J. Sci. 6:39-55
- Pande, S.K. (1958). Some aspects of Indian Hepaticology. (Presendial address). J. Indian bot. Sci. 37: 1-26.

- Pande, S.K. and Bharadwaj, D.C. (1949). Studies in Indian Hepaticae. IV. On some liverworts new to Indian flora. J. Indian bot. Soc. 28: 15-27.
- Pande, S.K. and Bharadwaj, D.C. (1952). The present position of Indian Hepaticology with a note on the hepatic vegetation of the country. Palaeo-bot. India 1: 368-381.
- Parihar, N.S. (1955). An Introduction to Embryophyta (Vol.I) Bryophyta. Central Book Depot, Allahabad. Pp 377.
- Proskauer, J. (1957). Studies in Anthocerotales. V.Phytomorphology 7: 113-135.
- Rayemaekers, G. (1987). Effects of simulated acidic rain and lead on the biomass and nutrient status, and heavy metal content of *Pleurizium schreberi* (Brid.) Mitt. J. Hattori Bot. Lab. 63: 219-230
- Remiers, H. (1954). Bryophyta, in A. Engler, H. Melchior and E. Werdermann, Syllabus der Pflanzenfamilien, 12 Auft. Bd., I Pp. 218-268
- Richardson, D.H.S. (1981). The Biology of Mosses. Oxford 220 Pp.
- Rothmaler, W. (1951). Die Abteilungen and Klassen der Pflanzen, Feddes Repert., 54:256-266.
- S.N. Pandey and P.S. Trivedi. A Text book of Botany. Vol I. Eleventh ed.
- Simon, T. (1975). Mosses as indicator organisms for soil conditions in steppe- forest ecosystems. XII Int. Bot.Cong.Abstr., Lenningrad, 1:87.
- V. Singh, P. C. Pande and D. K. Jain. A Text book of Botany. Rastogi Publication.
- V. Singh, P. C. Pande and D. K. Jain. Biodiversity of microbes and cryptogams. Rastogi Publication.
- V.P. Dube, M.U Charaya and Vasundhura Arora College Botany VOL I. Pragati Prakashan.
- Vashistha, B.R., Sinha, A. K. Dr.and Kumar, Adarsh. Dr. (2014). Botany for Degree Students: Bryophyta. S. Chand & Company Pvt. Ltd. New Delhi

2.10 SELF ASSESSMENT QUESTIONS

1. Discuss in detail the economic importance of Algae.
2. Describe the role of algae as a medicine.
3. What are the negative effects of Algae.
4. What is the role of Algae in Nitrogen fixation?
5. Write the ecological importance of Algae.
6. Describe the general characters of algae.
7. Describe the general characters of bryophytes.
8. Give an account on the distribution of bryophytes in India.
9. How are bryophytes useful in soil formation, soil conservation and succession?
10. Give an account on the role of bryophytes as pollution indicators.
11. What are the medicinal uses of bryophytes?
12. What is Peat? Describe importance of peat.
13. Describe the antibiotic activities of bryophytes.
14. Discuss the role of bryophytes as food, flavoring agent and clothing.
15. Describe the role of bryophytes in construction and horticulture.

16. Describe the anti tumor properties of bryophytes.
17. What are algae? Give the characteristic features of algae.
18. Describe the various pigments present in algae.
19. Describe the basic types of cell organelle in algae.
20. Write short notes on following:
    - i. Algal habitat
    - ii. Flagella in algae
    - iii. Structure of prokaryotic cell
    - iv. Eye spot in algal cell
    - v. Types of chloroplast found in algae

UNIT 3: PTERIDOLOGY AND GYMNOSPERMS

Contents:

3.1 OBJECTIVES

After reading this unit you will be able to:

- Describe habit and habitat of pteridophytes
- Describe the characteristic features of pteridophytes.
- Explain and define the meaning of gymnosperms.
- Describe the characteristic features of gymnosperms.
- Analyze the distribution and economic importance of gymnosperms.

3.2 INTRODUCTION

Pteridophyta: The term is derived from Greek word ***Pteron*** meaning a feather and ***Phyton*** meaning a plant therefore, pteridophyta is a group of plants with feather like appearance. This group includes higher cryptogams which are also known as **Vascular cryptogams**. The term **c**ryptogams (kruptos= hidden, gamos= wedded) was suggested by Linnaeus in 1754 for all non-flowering plants that reproduce by means of spores and do not produce seeds. The term **vascular** indicates the presence of vascular tissues (xylem and phloem) for the conduction of water and food. Thus, the vascular cryptogams or pteridophytes can be defined as an assemblage of seedless vascular plants that have successfully invaded the land and reproduce by means of spores. The main features of pteridophtes are:

1. These plants have an independent gametophyte and an independent sporophyte. This is contrast to the bryophytes where the sporophyte is a parasite on gametophyte and the gymnosperms and angiosperms where the gametophyte is a parasite on sporophyte.
2. The dominant phase of life-cycle is the sporophyte.
3. This was the first group of vascular plants to invade the land.
4. This was the first group to have a vascular system (xylem and phloem).
5. They do not produce seeds but produce spores.

They include most primitive living and fossil vascular plants. They are represented by about 400 living and fossil genera and some 10500 species. The fossil records indicated that these plants originated about 380 million years ago, in the Silurian period of the Palaeozoic era and formed dominant vegetation on earth during the Devonian period. The tree ferns, giant horse tails and arborescent lycopods dominated during this period.

"Some seeds are enclosed in a pod, some in a husk, some in a vessel, and some are completely naked"- **Theophrastus**

Gymnosperm: The term was given by Theophrastus in his book ***"Enquiry into Plants"*** (300 BC). It is derived from two Greek words, "***gymnos*****"** means naked and **"*****sperma*****"** means seeds. Gymnosperms and angiosperms are two groups of seed plants (Spermophyta). The former are naked seeded plants in which ovules are not enclosed by ovary wall, born freely on **open megasporophylls**, whereas in later, ovules are born in the **closed megasporophylls** and are completely enclosed within the ovary. Due to this reason (protected seed) angiosperms are considered to be advancedthan gymnosperms. As **gymnosperms** do not possess ovary, hence they don't produce fruits, whereas angiosperms possess ovary and produce fruits.

3.3 GENERAL FEATURES OF PTERIDOPHYTES

Habit and Habitat: The plant body is sporophytic, differentiated into root, stem and leaves (except in the most ancient fossil pteridophytes and the most primitive living members of the group). They show much variation in their form, size and habit. They range from small annuals (e.g. *Azolla*, *Salvinia*) to large tree like perennials (*Angiopteris, Osmunda*). The branching of the stem shows a range of variation. It may be monopodial and dichotomous. The adventitious roots arise on the stem or in many ferns on the petiole.

Most of the living pteridophytes are terrestrial, growing in moist and shady places. Some members (*Azolla*, *Marsilea*, *Savinia* etc) are aquatic and few forms grow (*Equisetum arvense*) in xerophytic habitats (Fig. 3.1).

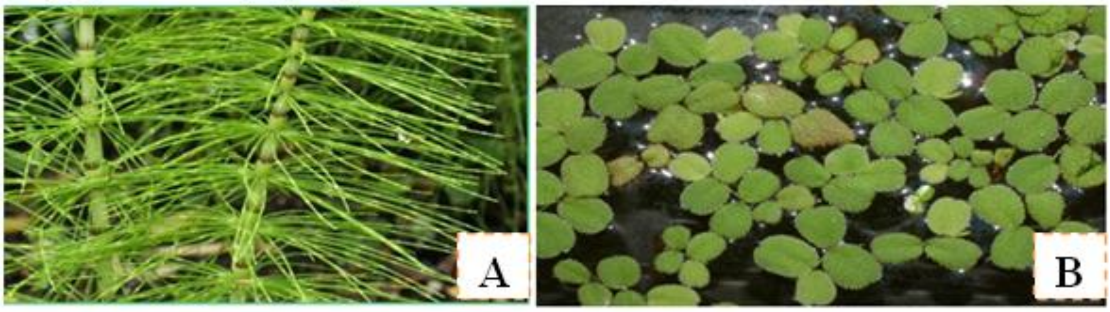


Fig. 3.1 Range of habitat A- Xerophytic (*Equisetum*); B- Aquatic (*Salvinia*)

The leaves are scaly (*Equisetum*), small and sessile (*Lycopodium*), or large, petiolate and compound (e.g. ferns) (Fig. 3.2). Based on size and venation pattern the pteridophytes are:

a. **Microphyllous:** Includes plants with small leaves. The microphyll is distinguished from the megaphyll by its simple venation (e.g. *Equisetum*, *Lycopodium*).
b. **Megaphyllous**: Includes plants with large leaves. Megaphyll is distinguished from microphyll by its complex venation (e.g. ferns).

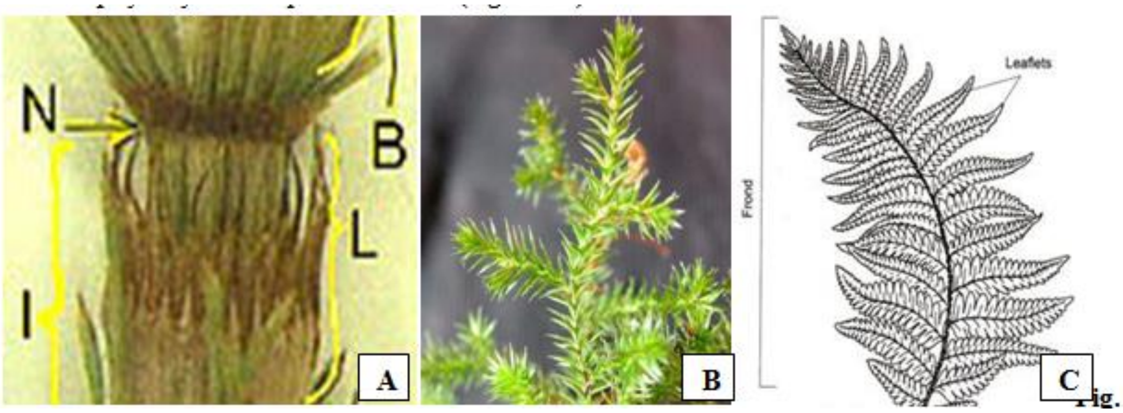


Fig. 3.2 Leaves in pteridophytes; A. scale leaves (*Equisetum*); B. microphyll (*Lycopodium*) ; C. megaphyll (*Dryopteris*).

Anatomical structure

The root and stem have well developed vascular system composed of xylem and phloem. Only the sporophyte shows any appreciable development of conducting tissues. The recorded instances of such tissue in gametophytes are rare and amount of xylem and phloem are scanty.

The stellar organizations are haplostelic protostele (*Selaginella*), plectostele (*Lycopodium*), siphonostele (*Equisetum*), dictyostele (*Pteris* and *Pteridium*) and polycyclic (*Marattia*) (Fig. 3.3). The xylem is made up of tracheids and phloem has sieve tubes only. Except for lower group the photosynthetic tissue is restricted only to leaves. The megaphyll show differentiation of the mesophyll into palisade and spongy tissues. The root shows a diarch structure which is almost constant throughout the pteridophytes and has been regarded as a conservative organ.

Sporangia: They reproduce by spores produced in sporangia. The sporangia are borne either on the leaves called sporophylls or in axils between the leaves and the stem (Fig. 3.4). Sporophylls are either uniformly distributed (*Pteris*) or are aggregated into compact ones (**strobilii**) at the apex of the stem (*Equisetum*). In aquatic forms like *Azolla* and *Marsilea* the sporangia are present within specialized structure called sporocarps. In some pteridophytes e.g. Filicales; the sporangia are aggregated in clusters known as **sorus/sori** Most of the pteridophytes produce only one type of spores and known as **homosporous** (*Lycopodium*) while some produce two different kinds of spore and known as **heterosporous** (*Selaginella*) (Fig. 3.5).

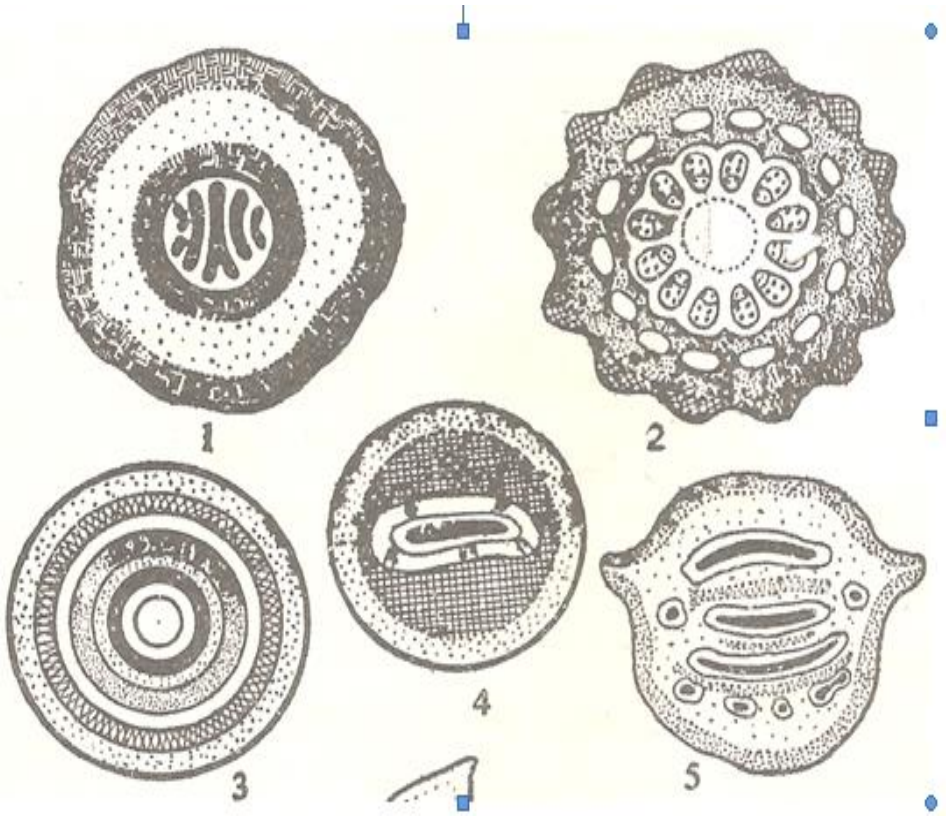


Fig. 3.3 Variation in stele in pteridophytes. 1. Plectostele (*Lycopodium*); 2. Siphonostele (*Equisetum*); 3. Polycyclic stele (*Marsilea*) 4. Haplostele (*Selaginella*) 5. Dictyostele (*Ptridium*).

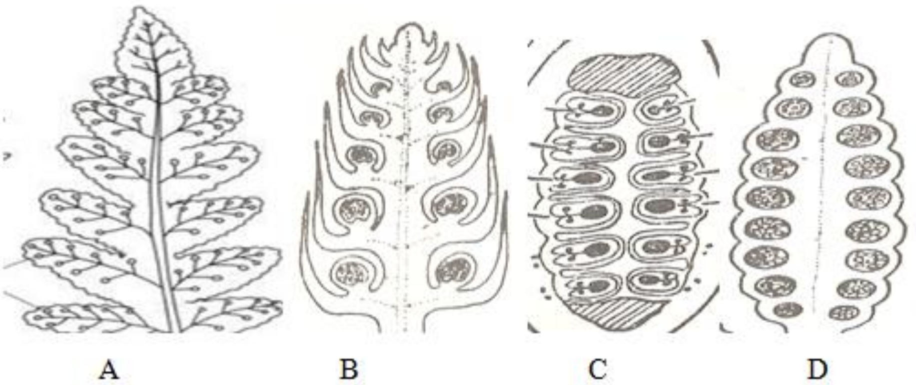


Fig. 3.4 Range of sporangial structure in pteridophytes A. Sporophyll (*Dryopteris*); B. Cone (*Lycopodium*); C. Sporocarp (*Marsilea*); D. Sori (*Ophioglossum*).

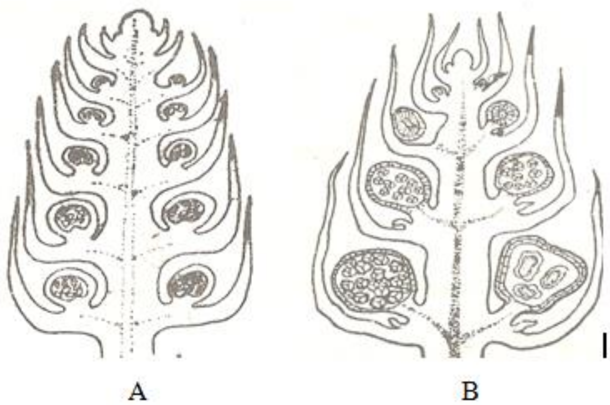


Fig. 3.5 Types of sporangium A. Homosporous (*Lycopodium*); B. Heterosporous (*Selaginella*)

The development of sporangia may be

a. Eusporangiate- The large sporangium initiated from a group of superficial cells which by periclinal division gives rise to outer layer of primary wall cell and inner layer of sporogenous tissue. e.g. *Psilotum*, *Lycopodium* (Fig. 3.6).

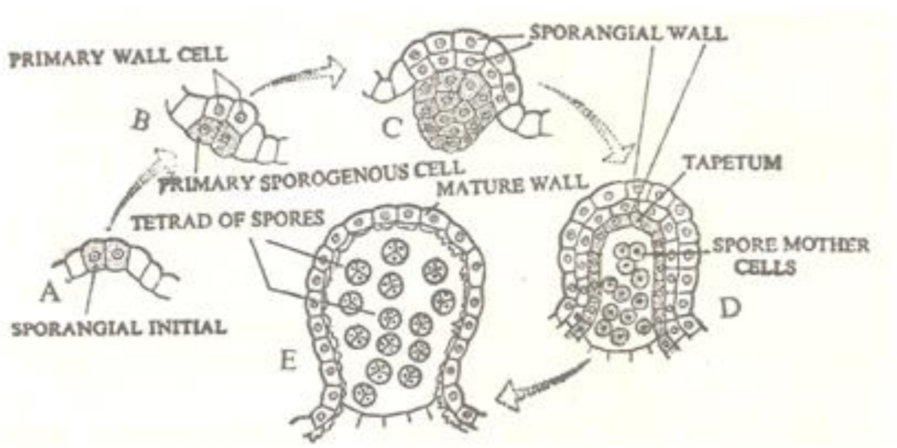


Fig. 3.6 Eusporangiate type of sporangial development

b. Leptosporangiate- The relatively small sporangium develops from a single initial cell which by periclinal division forms an outer and inner cell, the former forms the entire sporangium, its contents and stalk and the later do not take part in this process e.g. *Salvinia* and *Marsilea* (Fig. 3.7).

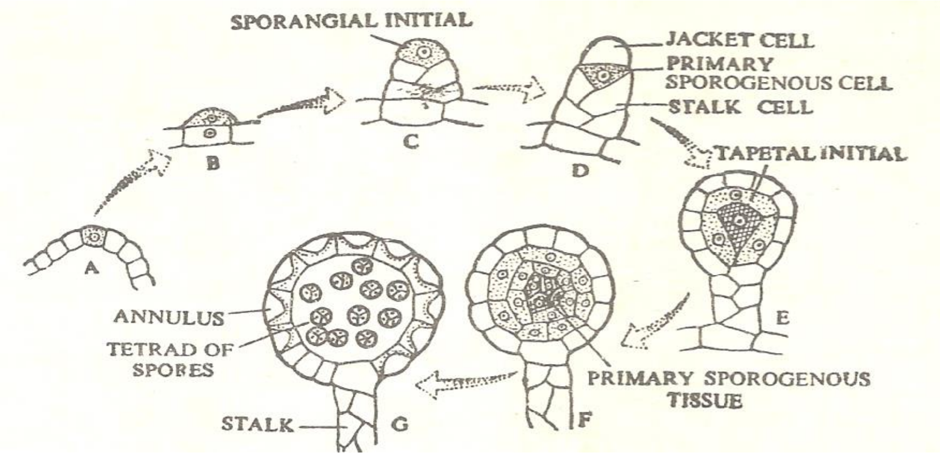


Fig. 3.7 Leptosporangiate type of sporangial development

Gametophyte: The haploid spores on germination give rise to the haploid gametophyte or prothalii. One of the most characteristic feature of pteridophytes is that the sporophyte has become the dominant part of life-cycle while the gametophyte has much been reduced. The gametophytes are of two types i.e. homosporous and heterosporous. In homosporous forms the gametophyte grows upon the soil and form independent plant. Such gametophytes are known as is exosporic gametophytes (*Psilotum*, *Lycopodium* and *Ophioglossum*). In heterosporous species gametophyte for most of its part is retained within sporangium and are called endosporic gametophytes (*Selaginella*, *Marsilea*, *Isoetes*). There is much variation in the shape and the size of the gametophytes (Fig. 3.8). In most of the vascular cryptogams, the exosporic gametophyte grow exposed to light and remain attached to the ground by many rhizoids (Fig. 3.8) In such cases they produce their food and live an independent life e.g. ferns. In some pteridophytes, exosporic gametophytes are devoid of chlorophyll and obtain their food by the symbiosis through mycorrhiza e.g. *Psilotum.* Such gametophytes are saprophytic in nature. The endosporic gametophytes are greatly reduced structures. They develop largely or entirely within spore wall and live on food deposits in the spore.

Sex organs: The gametophyte or prothallus bears the sex organs, the antheridia and archegonia. Gametophyte of homosporous species is monoceous that is both antheridia and archegonia are born in large number on the same gametophyte. In heterosporous species, gametophyte is dioecious that is antheridia and archegonia develop on different gametophytes. Antheridia may be embedded in the tissue or gametophyte or they may project from it. Former are embedded antheridia (*Lycopodium, Selaginella*) while the later are called projecting antheridia (leptosporangiate ferns). At maturity, antheridia are a globular structure with large number of androcytes. Each androcyte gives rise to a single motile antherozoid. The archegonium is a flask shaped structure consisting of a basal swollen embedded structure, the venter and a short neck. The venter encloses venter canal cell and neck canal cell are present inside neck. At maturity, the apical cell separate, the neck canal cell disintegrates forming a passage for antherozoid to reach egg.

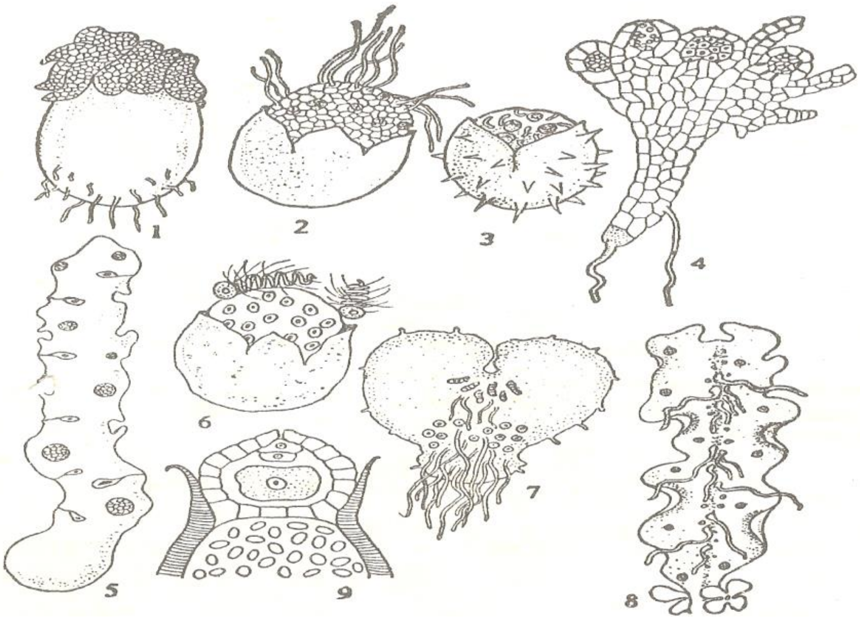


Fig. 3.8. Variations in the gametophyte of pteridophytes. 1. *Lycopodium*; 2. *Selaginella* (female); 3. *Selaginella* (male); 4. *Equisetum*; 5. *Ophioglossum*; 6. *Marsilea* (male) 7. *Pteridium*; 8. *Osmunda*; 9. *Marsilea* (female).

Fertilization: In all the cases fertilization takes place by the agency of water. The fusion of male gamete and egg give rise to a diploid zygote.

Embryo: The zygote divides to form an embryo which undergoes repeated divisions to form a new sporophyte

The pteridophytes occupy an intermediate position between bryophytes and spermatophytes, therefore, they show certain similarities with bryophytes on one hand and the spermatophytes on the other.

Resemblances with Bryophytes

The pteridophytes (vascular cryptograms) resemble the bryophytes in the following features:

1) Terrestrial habit.
2) Like the bryophytes, they reproduce asexually by means of spores. The spores are formed in the same manner in both the groups.
3) The sex-organs, the antheridia and archegonia are essentially identical as regards to their structure and ontogeny.
4) In both the groups, the sex-organs have sterile jackets around them.
5) The male gametes, *i.e.* the sperms are ciliated.
6) Fertilization takes place in presence of water.
7) Encapsulation of the embryo in the archegonium.
8) Dependence of early embryo (sporophyte) upon the gametophyte.
9) They exhibit regular interval of generations.

Differences between Pteridophytes and Bryophytes

The pteridophytes differ from bryophytes in the following features:

1) In the bryophytes, the gametophytes is the dominant and conspicuous generation, the diploid sporophyte being nothing more than a spore bearing structure and is dependent on the gametophyte for the nourishment. In the pteridophytes, it is sporophyte rather than the gametophyte which constitutes a large, conspicuous and dominant phase in the life cycle, while the gametophyte is always small and inconspicuous.
2) Plant body in pteridophytes shows differentiation into true roots, stem and leaves. In bryophytes, there may stem with leaves but there are no roots.
3) All the vegetative organs of sporophyte of pteridophytes possess vascular supply whereas bryophytes do not possess vascular tissue.
4) All bryophytes are homosporous, while pteridophytes may be homosporous or heterosporous.

Resemblances with Spermatophytes

The pteridophytes resemble the seed-bearing plants (spermatophytes) in the following features:

1) In both the groups, the sporophyte is the large, conspicuous, freely existing, independent and dominant phase in the life cycle. The sporophytic plant body is differentiated into true roots, stem and leaves.
2) All the vegetative parts of the sporophyte have typical xylem and phloem cells. The xylem consists of tracheids and xylem parenchyma, vessels being absent in majority of the pteridophytes (except *Selaginella* and *Marsilea*) and gymnosperms (except Gnetales). Phloem consists of sieve-tubes and phloem parenchyma. The companion cells being absent.

Differences between Pteridophytes and Spermatophytes

1) Pteridophytes differ from the spermatophytes in that they do not produce flower, fruits and seeds.
2) In pteridophytes, excepting few cases, the spores or gametophytes developed from them are invariably liberated from sporangia, instead of being permanently retained within them.
3) In spermatophytes, water is not necessary for fertilization.
4) Steles are more advanced in spermatophytes than those of pteridophytes.

3.4 GYMNOSPERMS: General Introduction

The first glimpse of this group shows that there are two distinct lines, namely the **Cycadophytes** and the **Coniferophytes** (Fig. 3.9).The former can easily be distinguished by some simple characters such as, **palm like tree habit, unbranched stem with long and large compound leaves**, whereas the latter has **cone shaped plant body, tall and profusely branched stem with acicular leaves.**

Of the living and fossil gymnosperms, Cycadales and Ginkgoales are very ancient, for this reason and with some other primitive characters, these members are called **"living fossils".** They include 11 genera with limited distribution in the tropical and sub-tropical parts of the world.

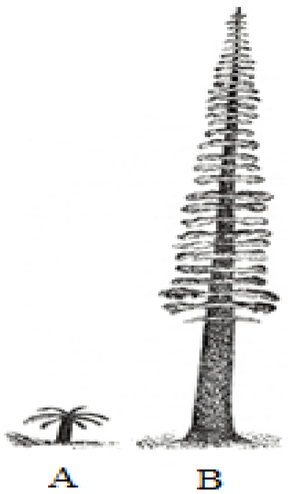


Fig. 3.9 Diagrammatic representation of the habit and comparative size of a Cycad (A) and a Conifer (B) - after Chamberlain (1935).

The second important group of gymnosperms is Coniferales. This group is most conspicuous, grows in nearly all parts of the world especially dominated in the Northern Hemisphere. Conifers are represented by nearly 50 genera with wide distribution in the temperate and sub-temperate parts of the world.

The next and most interesting group of gymnosperms is Ephedrales consisting of only three genera with great difference in their morphology and reproductive biology. One of the notable members *Ephedra* is found in the arid regions and can be identified by its shrubby leafless appearance. *Gnetum* is a woody liana and *Welwitschia* is underground perennial plant with two persistent leaves.

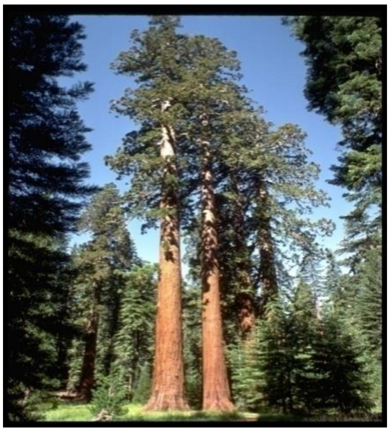


Fig. 3.10 Californian sequoia *(Sequoia semipervirens*)

You will be surprised to know that on one hand, the tallest tree known to plant kingdom belongs to gymnosperms- the Red wood plant or *Californian sequoia* (Fig. 3.10). The tree reaching a height of nearly 112 m into the sky and attaining a girth (diameter) of 15 m, is as tall as a 36 storey building (Laetsch, 1979). While on the other hand the smallest gymnosperm is a cycad, *Zamia pygmaea* (Fig. 3.11) in which the leaves are only 4 to 5 cm long and it attains a height of 25 cm only.

Goebel has rightly called gymnosperms as "phanerogams without ovary". Gymnosperms act as connecting link between pteridophytes and angiosperms. In plant kingdom the angiosperms have occupied the highest status while the position of gymnosperms is just before them. This is because of following reasons:

1. Gymnosperms have slow growth rate.
2. They lack vegetative means of reproduction such as cutting, layering, etc.
3. The means for dispersal of seeds of gymnosperms are very limited such as only by wind and man.
4. The seeds fail to grow under varied habitats (*e.g.* water).
5. Vessels are absent in xylem (except members of Gnetales) and companion cells are absent in phloem (except members of Gnetales).
6. There are less chances of self-fertilization because the cones are unisexual. Bisexuality is absent in gymnosperms.
7. A large amount of pollen is lost because of wind pollination.
8. Reduced chances of dispersal because their ovules and seeds are unprotected and they lack fruits.
9. Fertilization occurs through pollen tubes.

Fig. 3.11 *Zamia pygmaea*

3.5 GENERAL CHARACTERS OF GYMNOSPERMS

3.5.1 The Plant Body (The adult sporophyte)

3.5.1.1Geographical Distribution

Some groups of gymnosperms are entirely extinct, some groups are with primitive features and exist in both living and fossil states while some other are living gymnosperms that are distributed throughout temperate, tropical and even in arctic zones. Most of them are evergreen xerophytes.

3.5.1.2 External Features

1. Gymnosperms are middle sized trees (*Cycas*) to tall trees (*Pinus*) and shrubs (*Ephedra*). They are rarely woody climbers (*Gnetum montanum*). Herbs are not present in the gymnosperms.
2. The most massive (thick) and among the oldest, is *Sequoiadendron gigantium* (Big tree; Fig. 3.12) popularly known as Redwood tree or Father of forest. It attains 100 m height, 15 meters girth of trunk and live more than 4000 years.
3. Plants that are visible, are sporophytic generation (2n). These plants have slow growth rate. These are commonly of moderate size. But conifers are tall trees with graceful branches and foliage and present a conical appearance.

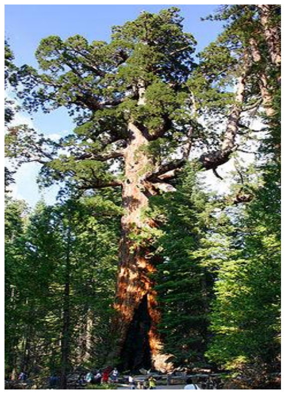


Fig. 3.12 Sequoiadendron gigantium

4. Usually tap root system is present but in some forms **symbiotic relationship** is found between roots and algae in **coralloid roots of *Cycas*** (Fig. 3.13) and between roots and fungi in **mycorrhiza roots of *Pinus*** (Fig. 3.14)**.**

5. The stems are aerial, erect, branched (unbranched in *Cycas* and *Zamia*) and woody. In *Pinus* branches are of two types *i.e.* **dimorphism**:-
   a) **Long shoots or branches of unlimited growth.**
   b) **Dwarf shoots or branches of limited growth** that on their apices bear cluster of variable number of needle shaped leaves, **collectively known as spur.**

Fig. 3.13 Coralloid roots of Cycas

Fig. 3.14 Mycorrhiza roots of Pinus

6. Plants may possess one kind of leaves *i.e.* **monomorphic** or two kinds of leaves *i.e.* **dimorphic**:-
   a) Foliage leaves (evergreen simple or compound).
   b) Scale leaves (minute and deciduous).
7. Leaves may vary in size from a minute scale leaf to a large and more than 2 meters long megaphylls of some cycads.
8. Venation may be reticulate (*Gnetum*) or parallel (*Welwitschia*) or dichotomous (*Ginkgo*).

3.5.1.3 Internal Features

1. Internal features of roots are like to dicotyledons. Vascular cylinder in roots is diarch to polyarch. Xylem is exarch and roots show secondary growth.
2. In *Cycas*, **a broad blue green zone called as algal zone, occurs in the middle cortex of coralloid roots**. The cells of this zone are not organized and are inhabited by the blue green algae *Anabaena cycadacerum* and *Nostoc*.
3. Vascular bundles of stems are collateral, endarch, open and are arranged in a ring. Secondary growth is also present. Secondary wood may be**monoxylic** (well developed pith and cortex) or **pycnoxylic** (much reduced pith and cortex). In cycads (*Cycas*) monoxylic wood is present while in others (*Pinus, Taxus*) it is pycnoxylic.
4. **Xylem lacks vessels and phloem lacks companion cells.**
5. **Secondary vasculature may be monoxylic (single layer of cambium) or polyxylic (several successive layers of cambium).**
6. Thick layer of cuticle and sometimes an additional layer of wax are present on leaves. Stomata are present in deep cavities. Mesarch

The following key may be used in the identification of the gymnosperms.

- Trees or shrubs are usually resinous.
- Herbs (annual) are completely absent.
- Ovules naked, not enclosed in an ovary.
- Cones unisexual, rarely bisexual.
- Leaves needle shaped or scale like, linear, pinnate, rarely fan shaped or oblong, elliptic mostly evergreen.

xylem and transfusion tissues are present. Mesophyll may be differentiated into palisade and spongy parenchyma (*Cycas*) or may be made of only one type of cells (*Pinus*).

3.5.3.1 Resemblances with Pteridophytes

1. Both show **heterologous alternation of generation**.
2. In both sporophytes are distinguished into root, stem and leaves.
3. Both possess **megaphyllous leaves**.
4. Both possess a well marked vascular system.
5. Both lack vessels in the xylem and companion cells in the phloem.
6. Both have **mesarch bundles** in their leaves.
7. Many pteridophytes are **heterosporous** like the gymnosperms.
8. Both possess endosporic gametophyte.
9. In both, gametophytes are highly reduced.
10. The male gametes of Cycads and *Ginkgo* are motile like those ofpteridophytes.
11. In both, female sex organs are archegonia.
12. In both, a distinct embryo develops after fertilization.
13. Embryogeny is **endosporic** in many pteridophytes and all gymnosperms.

3.5.3.2Differences between Gymnosperms and Pteridophytes

1. Gymnosperms are commonly large sized trees, shrubs or rarely climbers whereas pteridophytes are smaller in size and are herbaceous.
2. Gymnosperms have tap root system whereas pteridophytes have adventitious root system.
3. The stems of gymnosperms are aerial whereas the stem of pteridophytes is mostly underground rhizome.
4. All gymnosperms are heterosporous whereas most of pteridophytes are homosporus.
5. In all gymnosperms pollen tube develops as a result of germination of pollen grain, while in pteridophytes pollen tube is not formed.
6. In gymnosperms megaspores remain permanently in the megasporangium whereas in pteridophytes they are shed from the sporangium.
7. Megasporangium in gymnosperms is protected by an integument which is not found in pteridophytes.
8. Neck canal cells are absent in the archegonial neck of gymnosperms but are present in pteridophytes.

3.5.3.3 Resemblance with Angiosperms

1. Both have well developed and long lived sporophytic generation.
2. Both include trees and shrubs.
3. Sporophytes of both are differentiated into root, stem and leaves.
4. In both the groups root system is well developed.
5. The angiosperms and gymnosperms (except Gnetales) possess vessels in xylem and companion cells in the phloem.
6. Both have heterosporous sporophytes and endosporic gametophytes.
7. In both pollen grains grow into pollen tubes.
8. In most of gymnosperms and all angiosperms the male gametes are non motile.

9. In both nucellus is surrounded by integument to form ovule.
10. In both male gametophytes are highly reduced.
11. In both embryogeny is endosporic.
12. In both seeds develop from the ovule.

3.5.3.4 Differences between Gymnosperms and Angiosperms

1. Gymnosperms are not herbaceous whereas majority of angiosperms are herbaceous.
2. Majority of gymnosperms are perennials whereas angiosperms may be annual, biennial or perennial.
3. In angiosperms, xylem possesses vessels and phloem has companion cells, whereas in gymnosperms (except Gnetales) xylem is devoid of vessels and phloem lacks companion cells.
4. Gymnosperms are unisexual and may be monoecious or dioecious whereas angiosperms may be bisexual as well as unisexual, monoecious or dioecious.
5. Reproduction by vegetative means is very rare in gymnosperms whereas the method is very common in angiosperms.
6. The reproductive organs in gymnosperms are commonly called as cones or strobili whereas the reproductive organs in angiosperms are known as flowers.
7. In gymnosperms ovules are naked whereas in angiosperms they are enclosed within ovary.
8. Gymnosperms possess the archegonia whereas the angiosperms lack archegonia.
9. In gymnosperms endosperm develops before fertilization and is haploid (n) whereas in angiosperms it develops after fertilization and is triploid (3n).
10. Gymnosperms do not exhibit double fertilization which is commonly found in Angiosperms.
11. Polyembryony is mostly found in gymnosperms whereas it is not common in angiosperms.
12. In gymnosperms zygote shows free nuclear divisions whereas in angiosperms free nuclear divisions are absent.
13. In gymnosperms, seeds are exposed and fruits are not formed whereas in angiosperms seeds are enclosed in ovary and fruits are formed.

The above resemblances and differences between gymnosperms and other vascular plants show a close resemblance between them but also support that gymnosperms are an independent assemblage of plants that have certain characters peculiar to them alone. Thus gymnosperms occupy an intermediate position between pteridophytes and angiosperms.

3.6 DISTRIBUTION OF GYMNOSPERMS IN INDIA

The total number of living gymnosperms in world is approximately 72 genera and 725 species. M.B. Raizada and K.C. Sahni (1960) reported 16 genera and 53 species from India. Maheshwari listed only 14 genera. This lesser representation is due to the fact that gymnosperms are mainly dwellers of temperate regions and in India; such a climate is present only in the Himalayas. They form extensive dense forests and grow luxuriantly in various Himalayan ranges.

There are 6 living orders of gymnosperms and out of them 4 are represented in India. These are Cycadales, Coniferales, Ephedrales and Gnetales. *Ginkgo biloba* (living fossil-Ginkgoales) is cultivated at many places in India but it originally belongs to China.

Cycadales - Members of this order are tropical dweller. One of the living members, *Cycas* has 6 species distributed in India (Fig. 3.15). Out of the six species two are commonly grown in the Indian gardens.

Cycas beddomei : Restricted to dry hills of Cuddapah in the Andhra Pradesh.

C. circinalis : Found wild in the dry deciduous forests of south India.

C. pectinata : Grows wild in several parts of eastern India.

C. rumphii : Grows in Andaman& Nicobar Islands.

C. revoluta : It is a Japanese species, now cultivated as an ornamental plant in Indian gardens and is propagated vegetatively by means of bulbils. It is represented only by female plants, in India.

C. siamensis **:** Distributed in Siam, Burma, Cochin and Yunnan and grown in India as an ornamental plant.

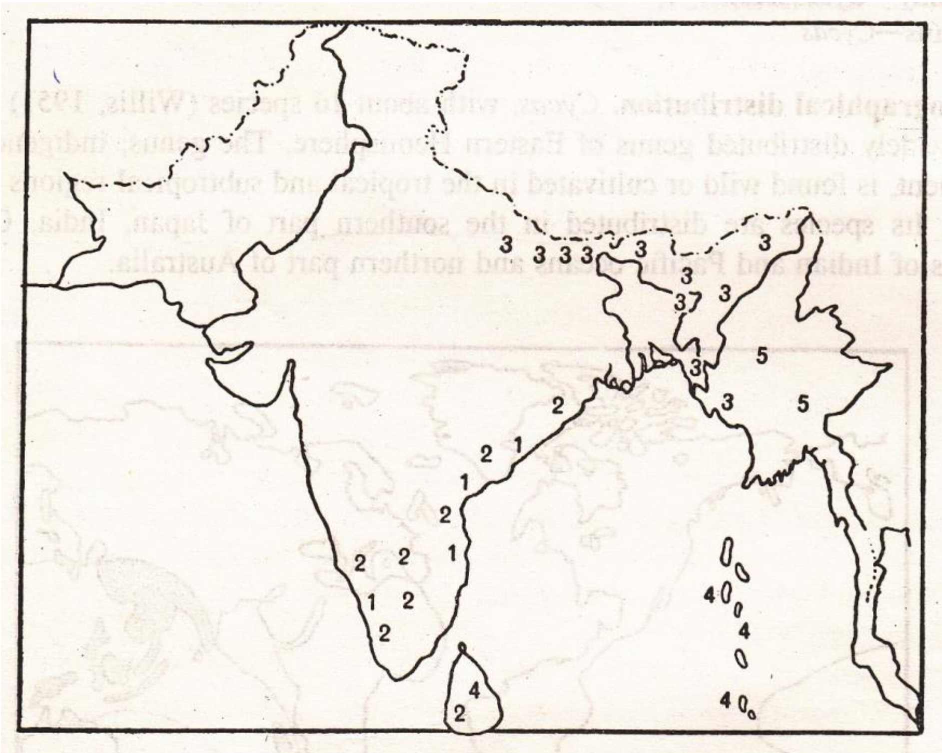


Fig. 3.15 Map showing distribution of *Cycas* in India and adjacent countries; 1. *C. beddomei*, 2. *C. circinalis*, 3. *C. pectinata*, 4. *C. rumphii*, and 5. *C. siamensis*

Coniferales - The order Coniferales is a large order represented by 11 genera in India. These include *Abies, Cedrus, Cephalotaxus, Cupressus, Juniperus, Larix, Picea, Pinus, Podocarpus, Taxus,* and *Tsuga.* **All of them except *Podocarpus* are found to the Himalayas, s**ome of them occur in both the Eastern and Western Himalayas, whereas others are restricted in distribution. **The distribution is governed mainly by altitude.** The important Indian species with their distribution are as follows:

i. ***Pinus*** is among the common gymnosperms and its species are distributed from Eastern to Western Himalayas (Fig. 3.16).

Pinus roxburghii : Grows luxuriantly at 1000 m a.s.l. in Western Himalayas.

P. wallichiana : Grows at 2,500 m a.s.l. in Western Himalayas.

P. kesiya : It also known by its synonyms as *P. insularis* or *P. khasyana.* It *g*rows luxuriantly in Eastern Himalayas. In Khasia and Chitagong hills from 800 to 1600 m a.s.l.

P. armendii : Grows luxuriantly in Arunanchal Pradesh upto 1500m a.s.l.

P. gerardiana : W. Himalayas from 1800 to 3000 m a.s.l. It forms forests in Kilba and Rampur Bushair (H.P.) and extends upto Kishtwar valley but not to Kashmir.

P. merkusii : In India, it occurs mainly in the Eastern part of Anjaw district of Arunachal Pradesh which is neighboring to the India–Myanmar Pine Forests Eco-region.

ii. ***Abies***: In India, *Abies* has four species out of which *A. pindrow* and *A. spectabilis* grow in Western Himalayas. These two species also grow along the higher ranges of Western and Central Himalayas 2300-4000m a.s.l.

iii. ***Tsuga*** trees attain a diameter of 6 meters and grow abundantly at 2,750 meters in Darjeeling.

iv. ***Cedrus deodara*** is the only Indian species that grows in Western Himalayas between **1200-3300 meters. It grows to huge size and may attain an age of 704 yrs.**

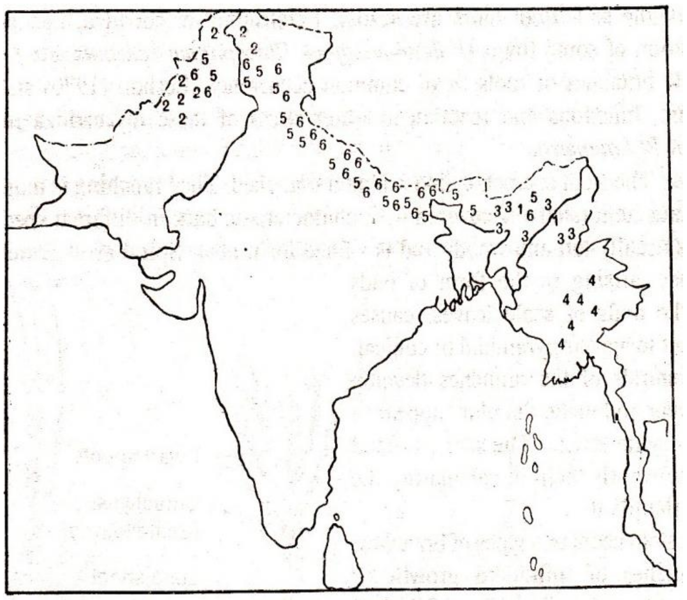


Fig. 3.16 Map showing distribution of Pinus in India and adjacent countries; 1. *P. armendii*, 2. *P. gerardiana*, 3. *P. kesiya*, 4. *P. merkusii*, 5. *P. roxburghii* and 6. *P. wallichiana*

v. ***Cupressus torulosa*** grows along with *Cedrus deodara* but also grows elsewhere throughout the outer and middle ranges of Himalayas from Chamba (H.P.) to the Aka hills (NEFA) at 1,800 to 2,800 m. *Cupressus sempervirens and Cupressus funiberus* is cultivated as ornamentals in Indian gardens.

vi. *Cephalotaxus* is represented by *C. mannii* and *C. griffithii* in India. Both grow in Eastern Himalayas and **are small trees,** 1500-1800m.

vii. *Juniperus* is represented by 6 species that grow in higher attitudes in the inner valleys of Eastern and Western Himalayas. They **grow above the tree limit** in the sub alpine and alpine regions.

J. communis is about 0.6 m high and forms more and less compact patches of few square meters at 2,900m to 4,250 m a.s.l. in the Garhwal Himalayas.

J. wallichiana with low spreading branches is 30 cm to 1.5 m high and forms dense patches upto 0.2 hectare in extent at 2,900 to 4,200 m.

J. recurva and *J. Squamata* grow from 2,300 to 4,900 m in Eastern Himalayas.

J. macropoda grows from 3,000 to 3,600 m in Ladakh and Kumaun and from1,500 to 4,300 m in Alaknanda valley (Uttarakhand).

J. coxii grows at higher attitudes in both the Western & Eastern Himalayas.

viii. ***Larix griffithiana*** **is the only deciduous conifer of India** that grows in Sikkim and through Chumbi Valley of Tibet to Bhutan and the Mishmi hills of NEFA, usually above 3,000 m.

ix. ***Podocarpus*** has two Indian species:-

P. neerifolia grows wild in the Andaman Islands and in Eastern Himalayas. It is a graceful tree growing up to 900 m. It is commonly found in the evergreen climax forests.

*P.wallichaina*occurs from Nilgiri south wards and in Assam. It is the only Conifer occurring in Nicobar Island.

x. ***Taxus baccata*** grows in the Westernas well as in Eastern Himalayas. **It loves moist and shady places above 2000 m**. It grows all along the Khasi-Jaintia and Naga hills.

xi. ***Cryptomeria japonica*** is **native of Japan** and **was introduced** into India in the nineteenth century. Now it has become **naturalized in Western Himalayas**.

xii. ***Thuja occidentalis*** is cultivated as an ornamental plant in North India.

xiii. ***Araucaria cookie*** and *A. cunninghamii* are cultivated as ornamental plants in North India.

Ephedrales: The genus *Ephedra* is represented by 6 species in India (Fig. 3.17), which are erect or climbing shrubs or perennial herbs. These species occur as following.

Ephedra foliata	: From Sind, Punjab and Rajasthan.
E. intermedia	: Grows in Kashmir, Punjab, Himachal Pradesh and Uttarakhand.
E. gerardiana	: Grows in dry alpine and temperate Himalaya in Sikkim and Kashmir.
E. saxatilis	: Grows in Sikkim.
E. nebrodensis	: High altitudes in the Himalayas.
E. regeliana	: Drier parts of Rajasthan.

Gnetales: It is represented by single genus *Gnetum,* grows in various parts of India. Five species have been reported which are:

G. ula	: Very common in the evergreen forests of Western Ghats, Andhra Pradesh and Orissa.
G. contractum	: It grows in Nilgiri Hills and Kerala and is a scandent shrub.
G. montanum	: Grows wild in Assam, Sikkim and some parts of Orissa.

G. lattifolium : Grows in the Andaman Islands.

G. gnemon : Is an erect shrub that grows in the rain forest of Eastern parts of India.

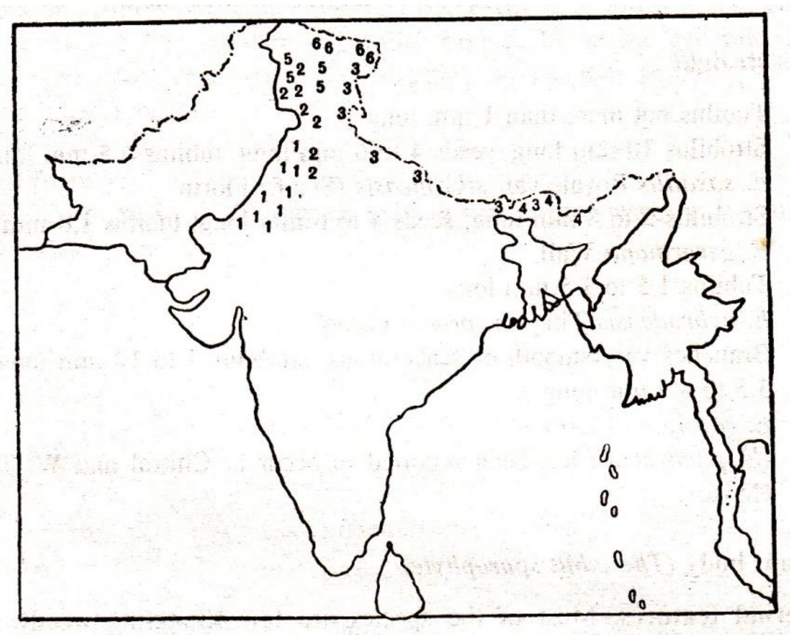


Fig. 3.17 Map showing distribution of Ephedra species in India and adjacent countries; 1. E. foliata, 2. E. intermedia, 3. E. gerardiana, 4. E. saxatilis, 5. E. nebrodensis, and 6. E. regeliana

3.7 ECONOMIC IMPORTANCE OF GYMNOSPERMS

The gymnosperms are an economically important group of plants spread all over the globe, primarily in the temperate (colder) and at higher elevations in the tropics (warmer) regions. **The trees are used for landscaping, timber, building constructions, resins and for manufacture of paper and board. They are also used in medicines, perfumes, varnishes and as essential oils.** The following headings give a brief account of the economic uses of various gymnosperms (Maheshwari & Singh 1960; and Bhatnagar & Moitra, 1997).

Wood: The coniferous wood is generally light coloured, straight grained and light weighted wood, which you might have observed in carpentry shops or in any pine forest. Such wood takes a good polish and paints easily. It bears good nail taking properties and takes a good finish with sharp tools. These properties make the wood used widely for cabinet and furniture making and interior decoration.

The wood of *Pinus* spp. (Pine) is used for making cheap furniture, packing cases agricultural implements, fencing poles, crates, doors, frames, toys, general mill work, etc.

Cedrusdeodara (Cedar or deodar) yields the strongest Indian timber. The heart wood is strongly scented and resistant to insect and fungal attacks. It is widely used for making railway sleepers and carriages. In North India it is chiefly used for making window panes, doors, furniture, electric poles, for flooring in houses, building models, boats, storage vats and also for battery separators.

Resin: Resins are plant exudates secreted in specialized ducts. These largely come from conifers as a result of tapping. They are insoluble in water and soluble in organic solvents and find a lot of use in varnishes, paints, medicines and in paper sizing. Various kinds of resins and their source are given below:

Rosin: It is obtained as a residue after the distillation of pine oleo-resin or turpentine. Turpentine is chiefly tapped from different species of *Pinus e.g., P. roxburghii*, *P. wallichiana*, *P. kesiya* and *P. merkusii*. Rosin is used in paper sizing, varnish making, enamels and in the preparation of plasters and ointments.

Copal: Copal is tapped from *Agathis australisas* a "green gum" or "candle gum". It is used in spirit varnishes, in making linoleum, preparation of plastics, polishes and the articles for which rosins are used.

Canada balsam: Canada balsam is obtained from *Abies balsamina*. It has a high refractive index as that of glass and is used as a mounting medium for microscopic objects and as a cement for lenses in optical work.

Essential oils: Various kinds of essential oils are obtained from different species of coniferous plants. An essential oil obtained from *Cedrusdeodara* is used in perfumery and in medicines to cure bronchitis, tuberculosis, skin diseases and gonorrhoea. Turpentine oil is a very popular essential oil obtained from several species of *Pinus*. Species of *Cupressus* (fir) and *Juniperus* (Juniper) furnish essential oils which are used in making incense sticks and perfumery.

Paper: Paper is made from wood pulp of some Indian species of coniferous plants like species of *Picia*, *Pinus, Abies*, *Cryptomeria* and *Gnetum*. Various species of *Pinus* provide newsprint almost all over the world.

Food: The stem and seeds of *Cycas* yield a starch "Sago" or "Arrowroot" Seeds of *Pinus gerardiana* (Chilgoza) and other species of *Pinus* are edible and nutritive. Young leaves and strobili of *Gnetum gnemone* are cooked as vegetable.

Medicines: Various gymnosperms yield essential oils and resins that possess medicinal properties. Resin obtained from *Cycas rumphii* is applied to ulcers. The wood of *Cedrus deodara* possesses diuretic and carminative properties and is used in curing pulmonary disorders, piles and rheumatism.

The oleo-resin of *Pinus* is used in gonorrhoea. Seeds of *P. gerardiana* yield oil which is applied as dressing to wounds and ulcers. The leaves of *Taxus baccata* (Yew plant, Thuner) are used in asthma, bronchitis, epilepsy and for indigestion. The alkaloid ephedrine extracted from green branches of *Ephedra* spp. is used against asthma, hay fever and bronchial inflictions. The seed juice of *Ephedra* is used to cure respiratory problems.

Ornamentals: Several species of *Cycas* are widely grown as garden plants and for decorative purpose. *Thuja* (biota, morpankhi) and species of *Juniperus* (juniper), *Cupressus* (cypress), *Araucaria* (Christmas tree) *Pinus* (pine), *Ephedra* (joint-pine, joint-fir), *etc*. are grown as ornamentals.

Besides, all these uses, the coniferous forests provide a cool and soothing climate suitable for health. Several health resorts and sanitoria run in the hills under the shadows of pine trees where hundreds of people and patients go every year for recreation and treatment.

3.8 SUMMARY

Vascular plants are traditionally divided into those that do not produce seeds- vascular cryptogams (pteridophytes) and those that produce seeds- spermatophytes. The modern pteridophytes are remnants of much larger groups that flourished 395 to 260 million years ago. The psilopsids, the club mosses, the horsetails and the ferns are the spore-bearing tracheophytes (due to the presence of trachieds or tracheary elements) and are collectively referred to as lower vascular plants or vascular cryptogams.

In pteridophytes the sporophytic plant body is differentiated into true roots, stem and leaves except some primitive members like *Rhynia*. The vascular system varies in different groups. It may be a simple protostele, dictyostele, solenostele or polycyclic stele. The sporophytic plant reproduces asexually by means of spores which are produced in sporangia. Development of sporangia may be eusporangiate (group of initial cell participate) or leptosporangiate (single initial cell participates). Sporangia are borne on stem or leaves or in their axils. Spore bearing leaves are called sporophylls. In some species, sporophyll are clustered to form cone or strobilus e.g. *Equisetum*, while in some other species sporangia are produced within specialized structure called sporocarp e.g. *Marsilea*. In ferns, sporangia are grouped together to form sorus. If all the spores are of same size, the plant is said to be homosporous (e.g. *Lycopodium* and *Equisetum*) and if they are of different size the plant is called heterosporous (e.g. *Selaginella* and *Marsilea*).

Gymnosperms are naked seeded, woody, perennial, xerophytic and evergreen plants. Plants possess tap root system but in some plants additional symbiotic relationship is found between roots and algae in coralloid roots (*Cycas*) and between roots and fungi in mycorrhiza roots (*Pinus*). Plants are heterosporous. Both dioecious and monoecious plants are found. Leaves possess thick cuticle, sunken stomata, mesarch xylem, transfusion tissue and may possess resin passage or latex tubes. Male cones are usually short lived and smaller while female cones are long lived and larger than the male cones. Microsporangia (male spore bearing organs) are borne on the lower surface of microsporophylls while megaporangia (ovules) are produced on the upper surface of the megasporophylls. Pollination is anaemophilous, *i.e.* takes place by means of wind. Mature embryo is divided into root, stem and leaves. Polyembryony (development of several embryos in a seed) is common feature of *Pinus.*

Economically gymnosperms are considered an important group which are the source of food, timber, paper, pulp, resin and drugs. The important drug ephedrine obtained from green branches of *Ephedra* is widely used in cold, asthma, bronchitis, etc.

3.9 GLOSSARY

Adventitious : Found in an unusual place *e.g.* adventitious roots.

Alternation of generation: The occurrence in one life differently produced, usually an alternation of a sexual with asexual form.
Asexual: Having no sexual organs.
Axis: The main stem of a whole plant or inflorescence.
Binomial nomenclature: The system of classification in which the scientific name of a species is a combination of two names, the first name being the generic name. The second name is referred to botanically as the specific epithet.
Cambium: The tissue from which secondary growth arises in stem.
Cone: The male or female flowers of gymnosperms with a central axis and spirally arranged sporophylls.
Coralloid: Branching like a coral *e.g.Cycas* roots
Cortex: The extrastelar fundamental tissue of the sporophyte.
Cryptogams: Plants whose sexual reproductive organs are not conspicuous and without stamens, ovaries and seeds. These plants produce spores.
Diarch: With two xylem and two phloem bundles.
Dichotomous: Repeated forking.
Dichotomous: The type of branching in plants that result when growing point divides into two equal growing points which in turn divide in a similar manner after a period of growth and so on.
Dictyostele: A siphonostele that is broken up by crowed leaf gaps into a network of distinct vascular stands or meristeles, each surrounded by an endodermis.
Dioecious: Having male and female sexes on different individuals.
Ectopholic: A stele with phloem present only on the external side of the xylem.
Embryo: A young organism in early stages of development.
Endodermis: Innermost layer of cortex in plants.
Endosperm: The nutritive tissue of seed.
Epidermis: The outermost protective layer of stem.
Erect: Directing upwards.
Evolution: The gradual development of organisms from pre existing organisms since the dawn of life.
Exarch: With protoxylemtowards periphery.andmetaxylemtowards the centre.
Fern: Any of numerous flowerless and seedless plants having true roots from a rhizome and fronds that uncurl upward and reproduce by spores.
Fertilization: The union of male and female nuclei.
Fertilization: The union of two similar or dissimilar gametes to form a diploid zygote.
Fossil: Petrified plant parts found in rocks.
Gametes: Sexual cells.
Gametophyte: A gametophyte is a gamete bearing plant. It develops from the meiospores produced by sporophyte by meiosis or reduction division. Gametophyte is a haploid structure.
Gametophyte: The gamete forming phase in alternation of plant generations, sexual generation of plants.
Habit: The general external appearance of a plant, including size, shape, texture and orientation
Habitat: The locality or external environment in which a plant lives.
Habitat: The place where a plant lives; the environmental conditions of its home.

Haploid: Having x number of chromosome (n).
Heteromorphic: Two stages morphologically different in shape, size, texture and orientation.
Heterosporus : Producing two kinds of spores, *i.e.* Microspores and Megaspores.
Heterospory: The condition of producing two types of spores differing in size.
Homospory: The condition of producing only one type of spores.
Leaf gap: Gap in vascular cylinder of a stem in parenchymatous region associated with leaf traces.
Leaf let: Individual unit of a compound leaf; pinna.
Leaf trace: The conducting strand extending from the stele of the stem through the cortex to the base of leaf and connecting the vascular system of both.
Leptosporangiate: Sporangia developing from a single initial cell.
Life-cycle: In most of the plants multicellular diploid sporophyte phase alternates with a multicellular haploid gametophyte phase. This cycle is known as life-cycle or alternation of generation.
Life-cycle: The various phases through which an individual species passes to maturity.
Megasporangium: A diploid spore sac containing only large asexual spores or megaspores.
Megaspore: The larger of the two kinds of asexual haploid spores, which produces female gametophyte in heterosporous plants.
Megasporophyll: A fertile leaf developing megasporangia.
Meristele: The vascular part of a dictyostele between two neighbouring leaf gap, appearing in transverse section as separate strands.
Mesophyll: The internal parenchyma of a chlorophyllous leaf.
Microsporangium: A diploid spore sac containing only small asexual spores or microspore.
Microspore: The smaller of the two kinds of asexual haploid spores, which produces male gametophyte in heterosporous plants.
Mid-rib: The large central vein of a leaf.
Monoecious: With sex organs on one gametophyte.
Monopodial: The mode of stem branching in which the main axis is formed by a single dominant meristem
Mycorrhiza: Association of fungal mycelium with roots of a higher plant.
Order: A group of one or more families sharing common features, ancestry or both
Ovule: The megasporangium of seed plant.
Palisade: Arrangement of opposed elongated cellular structures.
Pinnate: A compound leaf having leaf lets on each side of an axis or mid rib.
Pinnate: A compound leaf with leaflets arranged on each side of a common petiole or axis
Pollen: The powder produced by anthers consisting of pollen grains.
Pollination: Transference of pollen grains from anther to ovule.
Polyembryony: Formation of several embryos in one ovule *e.g.Pinus*.
Pteridophyte: Plants having vascular tissue and reproducing by spores
Rachis: The axis bearing leaf-lets.
Resin: An acidic excretion product of certain plants.
Root: Descending portion of plant, fixing it in soil and absorbing moisture and nutrients.
Shoot: Stem of a vascular plant derived from the plumule.

Siphonostele: A medullated protostele.
Sorus: A group of sporangia as in ferns.
Spore: A haploid propagule produced by meiosis in diploid cells of a sporophyte that can germinate to develop a multicellular gametophyte.
Spore: A highly specialized reproductive cell of plants.
Sporophyte: A sporophyte is the diploid multicellular stage in the life cycle of a plant. It develops from the zygote when a haploid egg cell is fertilized by a haploid sperm and each sporophyte cell therefore has a double set of chromosomes. The sporophyte produces spores by meiosis (hence the name sporophyte means spore bearing plant).
Stele: The central vascular cylinder of the axis (stem and root) taken as whole.
Strobilus: A cone like structure consisting of sporophylls or sporangiophores borne close together on an axis.
Tracheid: One of the cells with spiral thickenings or bordered pits, conducting water and solutes, and forming woody tissue.
Vascular bundle: A group of special cells consisting of two parts, xylem and phloem.
Vascular: An adjective referring to the conducting tissues (xylem and phloem) in vascular plants.
Vertical: Standing upright.
Xylem: Lignified portion of vascular bundle.

3.10 REFERENCES

Andrews, H.N. 1960.*Evolutionary trends in early vascular plants,* Cold Spring Harbor Symposia on Quantitative Biology 24: 217-234.

Arnold, C.A. (1948), “Classification of gymnosperms”, *Botanical Gazette*, Vol. 110, pp.2-12.

Benson, L. 1957. *Plant classification*. Boston

Bentham, G. and Hooker, J.D, (1862-1883), *Genera Plantarum*. L. Reeve& Co., London.

Bhatnagar, S.P. and Moitra, A. (1997), *Gymnosperms*. New Age International (P) Limited, New Delhi.

Bierhorst, D.W. (1971), *Morphology of vascular plants*, Mac. Millan Co., New York.

Bold, H.C.1957.*Morphology of plants*. New York.

Boodle, L.A.1901Comparative anatomy of the Hymenophyllaceae, Schizaceae and Glecheniaceae .*Ann. Bot*. 15: 703-747.

Bower, F.O. 1911. Medullation in the Pteridophyta. *Ann.Bot.* 25: 537-553.

Brongniart, A. (1843), *Enumeration des genres de plantes,* Paris.

Chamberlain, C.I. (1935),*Gymnosperms-structure and evolution*, Chicago.

Coulter, J.M. and Chamberlain, C.I. (1910), *Morphology of Gymnosperms*. Chicago.

Cronquist, A., Takhtajan, A. and Zimmermann, W. (1966), On the higher taxa of Embryophyta. *Taxon*.Vol. 15(4), pp.129-134.

Devevoryas, T. (1963),*Morphology and evoloution of fossil plants,*Hott, Rinehart & Winston, New York.

Engler, A. and Prantl, K. (1897), *Die naturlichenPflanzenfamilien*,Nachtragzu Teilen 2-4.

Gwynne-Vaughan, D.T. 1908. Observation on the anatomy of solenostelic ferns. *Ann. Bot.* 15: 71-78.

Hort, A. 1916. *Theophrastus: Enquiry into Plants,*

Jeffrey, E.C.1898. *The morphology of central cylinder in vascular plants*. Rep. Brit. Assoc. Toronto 869-70.

Laetsch, W.M. (1979), *Plants: Basic concept in Botany*, Scott Foresman & Co, USA.

Linnaeus, C. 1754. *Genera Plantarum*, Holmiae. Shattuk, C.H. 1910. Origin of heterospory in *Selaginella*. *Bot. Gaz*. 49:19-40.

Maheshwari, P. and Singh, H. (1960), Economic importance of conifers. *J. Univ. Gawhati (Sci)*, Vol. 11, pp.1-28.

Pant, D.D. 1957. The classification of gymnosperms plants.*Palaeobotanist*, Vol. 6(1), pp**.**188-203.

Raizada, M.B. and Sahani, K.C. (1960), Living Indian Gymnosperms, *Indian forest records: Botany*,Vol. 5 (2), Manager of Publications, New Delhi

Smith, R.W. 1955. *Cryptogamic Botany*. Vol II McGraw Hill, New York

Sporne, K.R. 1965. *The morphology of Gymnosperms*. London.

Takhtajan, A.L. 1964. Phylogenetic principles of the system of higher plants. *Bot.Rev*. 79: 1-45.

Thomas, H.H. 1950.The telome theory and the new morphology. *R. Proc. 7th Internat. Bot. Congress, Stockholm.ept.*

Van Tieghem, P. and H. Douliot 1886.Sur la polystelic. *Ann. Sci. Nat. Bot. Ser*. 7(3): 275-322.

Van Tieghem, Ph. 1898. *Elements de Botanique*. Ed. **3:** Paris.

Wilson, C.L. 1953. The telome theory. *Bot. Rev*. 19: 417-437.

Zimmermann, W. (1952).The main results of the Telome theory. *Palaeobotanist*, Vol. 1, pp. 456-470.

Zimmermann, W. 1930. *Die Phylogenie der Pflanzen, I,* Auflage, Jena.

3.11 SUGGESTED READINGS

Biology and morphology of Pteridophytes. Central Book Depot Allahabad By Parihar, N.S.

An introduction to Pteridophyta: Diversity and Differentiation. Vikas Publishing House Pvt Ltd, New Delhi By A.Rashid,

A Text Book of Pteridophyta . Vikas Publishing House Pvt Ltd, New Delhi By Pandey, S.N., P.S. Trivedi and S.P. Misra

Botany for Degree students: *Pteridophyta*. S. Chand Publications, Meerut By B.R.

Botany for Degree Students -Gymnosperms: P.C. Vashishta, A.K. Sinha and A. Kumar (1976).

College Botany. Vol. 2 : H.C. Ganguly and A.K. Kar (1999).

Gymnosperms: *Structure & Evolution*: C.J. Chamberlain (1935).

Gymnosperms : P.C. Vashishta (1976).

Gymnosperms of India and Adjacent countries: K.C Sahni (1990).

Gymnosperms: S.P. Bhatnagar and Alok Moitra (1997).

Gymnosperms: A Treatise: O.P. Sharma (1980).

Indian Gymnosperms in Time and Space: C.G. K. Ramanujan (1979).

Living Indian Gymnosperms: M.B. Raizada and K.C. Sahani, (1960).

A Text Book of Botany: V. Singh, P.C. Pande and D.K. Jain (2008).

The Moropology of Gymmosperms: K.R. Sporne (1991).

Important website and links

http://biology.clc.uc.edu/courses/bio106/gymnospr.htm(accessed on March, 2015).

http://www.biologyreference.com/Gr-Hi/Gymnosperms.html#ixzz3VIBvPMJk (accessed on March, 2015).

http://www.conifers.org (accessed on March, 2015).

3.12 TERMINAL QUESTIONS

1. Write a note on different types of stele in pteridophytes.

2. Discuss the characteristic features of pteridophytes in detail.

3. Write a note on Range of sporangial structure in pteridophytes.

4. With the help of diagram differentiate between

(i) Homosporous and heterosporous Pteridophyte

(ii)Eusporangiate and leptosporangiate type of sporangial development

5. Discuss the characteristic features of gymnosperms in detail.

6. Give an account on economic importance of gymnosperm.

7. Write notes of the following:

i. Resemblances with Pteridophytes
ii. Differences between Gymnosperms and Pteridophytes
iii. Resemblance with Angiosperms
iv. Differences between Gymnosperms and Angiosperms
v. Distribution of gymnosperms in India
vi. Coralloid roots and mycorrhiza roots
vii. Canada balsam, copal, resin and resin.

UNIT-04: INTRODUCTION TO ANGIOSPERM TAXONOMY

Contents:

4.1 OBJECTIVES

After reading this unit you will be able to understand:

- Classification and History of classification
- Aims of Taxonomy
- Bentham and Hooker's system
- ICBN or ICN
- Principles of ICBN
- Rules & recommendation

4.2 INTRODUCTION

Plant taxonomy is one of the earliest disciplines of Botany. It was started as "Folk Taxonomy" in early 15th century but it has grown and gone very long way in the last 500 years. The concept and scope of Taxonomy has changed a lot. Though the flora of the earth was invented in the last three centuries yet the modern taxonomists are facing challenges. The tropical countries with rich flora are under threat. So far 4,000,000 plant species are identified of which 2, 86,000 are of angiosperms. Among the identified plants about seventy percent belong to tropical regions.

In the modern times people are running for the applied sciences as cytology, genetics, experimental biology, ecology, molecular biology etc. but a few people are thinking of the basic or fundamental branches of botany like Taxonomy and Morphology. It has become an old fashion. No applied branch can be approached without the proper identification of the plant material on which he/she is working and for this taxonomists are very much needed.

With the increased need for conservation of biological resources, the need for biodiversity assessment during the last few years has increased. The trend has, however, reversed and taxonomic studies are being encouraged throughout the world.
Simpson (1961) suggested that systematics included identification, taxonomy, classification and nomenclature and used as the scientific study of the kinds and diversity of organism and of any and all relationship between them. de Candolle (1813) first coined the term taxonomy.

Introduction to Plant Taxonomy: Plant taxonomy is the branch of botany dealing with the Identification, Classification and Nomenclature of a plant on the basis of characteristics, similarities and dissimilarities of the characters. Various systematic activities are directed towards the singular goal of constructing an ideal system of classification that necessitates the procedures of identification, description, nomenclature and constructing affinities. This enables a better management of information to be utilized by different workers, investigating different aspects structure and functioning of different species of plant.

There are three main aims of taxonomy, *i.e.,* Identification, nomenclature and classification. There are two main approaches:

(a) **Empirical approach:** It is based on practical aspects, observation of characters etc.

(b) **Interpretive approach:** The classification is based on interpretation and evolution of a taxon, e.g., phylogenetic system. Modern taxonomy combines both approaches with the following aims:

1. To provide a convenient method of identification and communication.
2. To provide classification based on natural affinities of organisms as far as possible.
3. To provide an inventory of plant taxa by means of flora.
4. To detect evolution at work, discovering its process of interpreting into results.
5. To provide an integrating and unifying role in the training of biology students regarding the relationships between many biological fields and data gathering science.

The different components of plant taxonomy are as follows:-

Identification: Identification or determination is recognizing an unknown specimen with an already known taxon, and assigning a correct rank and position in an extant classification. In practice, it involves finding a name for an unknown specimen. This may be achieved by visiting a herbarium and comparing unknown specimen with duly identified specimens stored in the herbarium. Alternately, the specimen may also be sent to an expert in the field who can help in the identification. Identification can also be achieved using various types of literature such as floras, monograph or manuals and making use of identification keys provided in these sources of literature.

Classification: Classification denotes the arrangement of a single plant or group of plants in distinct category following a system of nomenclature and in accordance with a particular and well established plan. The basic unit of classification is species which are grouped into genus and further grouped into family suborder, order, subclass, classes and divisions.

The beginning of the classification of organism took place at remote times by the non civilized people for their usage and in their own language, with the development of language the distinction between carnivores, herbivores, poisonous plants, edible plants etc. became clear. They feel the necessity of different plants and animals for their use. They selected certain plants and animals for festivals. In this way, the classification in crude sense got the foothold in the society. Folk systematics is gaining popularity among the pre civilized men. They recognized groups of plants on the basis of gross morphology. This is the beginning of the artificial system of classification. Their ways of classification are rooted in their practical considerations. The history of classification starts from the time of the earliest Indian Philosophers like Charak, Sushruta, early Greek philosophers like Aristotle, Plato, Pliny and others also tried to classify plants from their own viewpoint which invariably were more philosophical in nature than scientific. The various classifications of plants proposed so far, belong to either of the three categories:

(a) Artificial: System classifies plants with the help of one or few characters, primarily with a intention of easy identification of the organism e.g. Banhin, Tournefort, John Ray, Carl Linnaeus.

(b) Natural: System is mainly based on from relationship realizing all informations available at that time. e.g., de Candolle, Robert Brown, de Lamarck, Bentham and Hooker's classification.

(c) Phylogenetic: System tries to classify plants based on their genetic relationships and according to their evolutionary sequences. e.g., Eichler, Hutchinson, Bessey.

C. Jeffrey (1982) presented that the system of classification can be divided into four main types:

(a) Artificial: Habit based classification made upto 1830.

(b) Pre evolutionary Natural Systems: Overall similarly between plants were much more natural e.g., Bentham & Hooker, A. P. de Candolle, de Jussieu.

(c) Phylogenetic Systems: Natural grouping as a result of decent or common character are related to each other through a common ancestry, e.g., Eichler, Engler.

(d) Phenetic System: Maximal generalizations of the totality of the features of all phenotypes e.g. Hutchinson.

History: History of taxonomy begins with the categorization of useful plants of folk taxonomy. People differentiated them as economic plants. This paved the way for herbal taxonomy. The history can be studied in different phases as follows:

I. Initial Stage: In initial stage taxonomy was merely started for exploration and naming of species.

- **Theophrastus** (370-285 BC) a Greek Naturalist also known as **Father of Botany** published "Enquiry into Plants". He proposed *Crataegus, Daucus* (daukan), *Asparagus* (aspargos) and *Narcissus* etc. in his work. He classified plants on habit base as herbs, undershrubs, shrubs, trees. He gives the name and description to 500 plants in *Historia Plantarum* oldest botanical work in existence. He pointed out the differences between dicots and monocots.
- Some other workers of this stage are Pliny (23-29 AD), Pedanion Dioscorides (62 - 128 AD), Andrea Caesalpin**o** (1519 - 1603 AD), Gaspard Bauhin (1560 - 1624 AD), John Ray (1628 - 1705 AD), J. P. de Tournefort (1656 - 1708) Carolus Linnaeus (1707 – 1778).

II. Natural System Stage

- Antoine L de Jussieu (1686 - 1758) published *Genera Plantarum* and classified plants into 15 classes.
- Augustin Pyrame de Candolle (1778 - 1841), a French botanist published *Theorie elementaire de la botanique* in 1813 and developed morphological approach to classification. He classified plants as Vasculares and Cellulares, Monumental works - *Prodromus Systematis Naturalis Regni Vegetabilis*. A. P. de Candolle could not complete his work and later his son Alphonse de Candolle completed the work.
- Charles Darwin (1859) published *Origin of Species*, where he suggested the principle of natural selection and evolutions of species.
- Bentham and Hooker (1800 - 1884) published *Genera Plantarum* (1862 - 1883) gave practical use of classification "ever since been as inspiration to generations of the Kew Botanists".

III. Phylogenetic Stage

- Phylogenetic classification was based on the ideas of evolution. It started with Endlichler (1804-1849) and Eichler (1837-1887).
- Engler and Prantl. (1887-1915) suggested semi-phylogenetic system of classification.
- *Die Natiirlichen Pflanzen Familien* (1887 - 1899) and S*yllabus der Pflanzen Familien* (1964). He placed monocots before dicots and orchids were considered more evolved than grasses.
- Class 1 : Monocotyledons - 11 orders
- Class 2 : Dicotyledons

- Sub class - 1. Archichlamydeae - 29 orders.
- Sub class 2. Metachlamydeae (Sympetalae) - 9 orders
- A. B. Rendle (1865 - 1938) Classification of flowering plants. He treated monocots as primitive to dicots and amentiferae and apetalous as primitive dicots.
- The first purely phylogenetic system based on *Dictas of Phylogeny* was given by Charles Edwin Bessey (1845-1915) which was improved by Hans Hallier (1868-1938)
- John Hutchinson (1884 - 1972)) Britishers, put forth his 24 principles of phylogeny and based on that suggested phylogenetic classification of value, in *Families of Flowering Plants* (1959). His classification was based as Bentham and Hooker and Bessey. First volume deals with Dicots (1928), second with Monocots (1934) and published *British Flowering Plants* (1940).

IV. Recent Stage

- The system was improved by contemporary Botanists like Takhtajan in *Flowering Plants: Origin and Dispersal* (1969); Cronquist in *"Evolution and Classification of Flowering Plants"* (1981) Stebbins in *Flowering Plant Evolution above the Species Level* (1974) and Robert Thorne in "*A Phylogenetic Classification of Angiospermae"* (1976) etc.
- The Classifications were based on distribution, Ecology, Anatomy, Palynology Cytology and Biochemistry apart from Morphology.
- Techniques of herbarium preparation and presentation were developed and established.

V. Biosystematic Phase

- The last fifty years have seen a qualitative improvement in the area of taxonomic concept and application by advancement of Biosystematics.
- The "New systematics" is aimed at achieving the goal of "holotaxonomy".
- Huxley (1940) proposed the term "New systematics."
- Camp and Gilly (1943) proposed the term "Biosystematics" to new systematics.
- The number, size and shape of chromosomes were considered by cytotaxonomists as very reliable parameters for cytotaxonomic classification.
- The development of techniques like two-dimensional paper chromatography, identification of chemical substances in plants as secondary metabolites led to the development of "Chemotaxonomy".
- The new techniques can give details as amino acid sequencing and determining nucleotide sequences in DNA and RNA.

VI. Holotaxonomic Phase

Information is gathered, analysed, and a meaningful inference is drawn for understanding phylogeny.

- Collection of data, analysis and synthesis are the jobs of an independent descipline of taxonomy, *i.e.,* Numerical Taxonomy.
- Numerical Taxonomy or quantitative taxonomy is based on numerical evaluation of the similarity between groups of organisms and the ordering of these groups into higher ranking taxa on the basis of these similarities.

Exploratory and Consolidation phase are considered as Alpha taxonomy while Biosystematic and Encyclopaedic phase are considered as Omega Taxonomy.

4.3 BENTHAM AND HOOKER SYSTEM OF CLASSIFICATION

The well known English systematists who brought out jointly '*Genera Plantarum*' (1862 - 1883) and their classification is used throughout the British empire. In our country the Central National Herbarium at Sibpur (Howrah) W. Bengal is maintained according to this system.

The system of classification is based on that of de Candolle, but greater stress is being given on the contrast between free and fused petals. The dicots are divided into Polypetalae, Gamopetalae and Monochlamydeae. The position of Gymnosperms between dicots and monocots is only for convenience rather than an indication of affinities.

An outline classification of Bentham and Hooker's system (1862 - 1883) is given below.

Class : Dicotyledons

Sub class 1 Polypetalae comprises three series

Series A: Thalamiflorae - 6 orders and 34 families

Order 1. Ranales - 8 families

Families: Ranunculaceae, Dilleniaceae, Calycanthaceae, Magnoliaceae, Annonaceae, Menispesmaceae, Berberideae, Nymphaeaceae.

Order 2. Parietales : 9 families

Families: Sarraceniaceae, Papaveraceae, Cruciferae, Capparideae, Resedaceae, Cistineae, Violaceae, Canellaceae, Bixineae.

Order 3. Polygalineae : 4 families

Families: Pittosporeae, Tremendreae, Polygaleae, Vochysiaceae.

Order 4. Caryophyllinae : 4 families

Families: Frankeniaceae, Caryophylleae, Portulacaceae, Tamariscineae.

Order 5. Guttiferales : 6 families

Families: Elatrineae, Hypericineae, Guttiferae, Ternstroemiaceae, Dipterocarpeae, Chlaenaceae.

Order 6. Malvales : 3 families

Families: Malvaceae, Sterculiaceae, Tiliaceae.

Series B: Disciflorae - 4 orders and 23 families

Order 7. Geraniales : 11 families

Families: Lineae, Humiriaceae, Malphighiaceae, Zygophyllaceae, Geraniaceae, Rutaceae, Simarubeae, Ochnaceae, Burseraceae, Meliaceae, Chaillentiaceae.

Order 8. Olacales : 3 families

Families: Olacineae, Ilicineae, Cyrilleae.

Order 9. Celastrales : 4 families

Families: Celastrineae, Stockhousieae, Rhamneae, Amplelideae.

Order 10. Sapindales : 5 families

Families: Sapindaceae, Sabiaceae, Anacardiaceae, Anomalous families Coriarieae and Moringeae.

Series C: Calyciflorae - 5 orders and 25 families

Order 11. Rosales: 9 families

Families: Connaraceae, Leguminosae, Rosaceae, Saxifrageae, Crassulaceae, Droseraceae, Hamomelideae, Bruniaceae, Halorageae.

Order 12. Myrtales : 6 families

Families: Rhizophoraceae, Combretaceae, Myrtaceae, Melastomaceae, Lythrarieae, Onagrarieae.

Order 13. Passiflorales : 7 families

Families: Samydaceae, Loaceae, Turneraceae, Passifloreae, Cucurbitaceae, Begoniaceae, Datisceae.

Order 14. Ficoidales : 2 families

Families: Cacteae, Ficoideae

Order 15. Umbellales : 3 families

Families: Umbelliferae, Araliaceae, Cornaceae

Sub class III Gamopetalae - Comprises three series.

Series A: Inferae - 3 order and 7 families.

Order 1. Rubiales : 2 families

Families: Caprifoliaceae, Rubiaceae.

Order 2. Asterales : 4 families

Families: Valerianeae, Dipaceae, Calyceerae, Compositae.

Order 3. Campanulales : 3 families.

Families: Stylideae, Goodeniaceae, Campanulaceae.

Series B: Heteromerae - 3 orders and 12 families

Order 4. Ericales : 6 families

Families: Ericaceae, Vaccinieae, Monotropeae, Epacrideae, Diapensiaceae, Lennoaceae.

Order 5. Primulales : 3 families

Families: Plumbaginaceae, Primulaceae, Myrsineae.

Order 6. Ebenales : 3 families

Families: Sapotaceae, Ebenaceae, Styraceae.

Series C: Bicarpellatae - 4 orders and 23 families

Order 7. Gentianales : 5 families

Families: Oleaceae, Salvadoraceae, Apocynaceae, Asclepiadaceae, Loganiaceae, Gentianaceae.

Order 8. Polemoniales : 5 families

Families: Polemoniaceae, Hydrophyllaceae, Boraginaceae, Convolvulaceae, Solanaceae.

Order 9. Personales

Families: Scrophalariaceae, Orobanchaceae, Lentiburaceae, Columelliaceae, Gesneraceae, Bignoniaceae, Pedalineae, Acanthaceae.

Order 10. Lamiales : 5 families

Families: Myoporineae, Selagineae, Verbenaceae, Labiatae, Anomalous family Plantagineae.

Sub class III. Monochlamydeae or Incomplete comprises A-H or 8 series.

Series A. Curvembyae : 7 families.

Families: Nyctagineae, Illecebraceae, Amarantaceae, Chenopodiaceae, Phytolaccaceae, Batideae, Polygonaceae.

Series B. Multiovalatae Aquaticae : 1 family

Family: Podostemaceae.

Series C: Multiovulatae Terrestris : 3 families.

Families: Nepenthaceae, Cytinaceae, Aristolochieae.

Series D: Microembryae : 4 families.

Families: Piperaceae, Chloranthaceae, Myristicaceae, Monimiaceae.

Series E: Daphnales : 5 families

Families: Laurineae, Proteaceae, Thymeleaceae, Penaeaceae, Elaeagnaceae.

Series F: Achlamydosporeae : 3 families

Families: Loranthaceae, Santalaceae, Balanophoreae.

Series G: Unisexuales : 9 families

Families: Euphorbiaceae, Balanopseae, Urticaceae, Platanaceae, Leitneriaceae, Juglandeae, Myricaceae, Casurinaceae, Cupuliferae.

Series H: Ordines Anomali (Anomalous families : 4)

Families: Salicaceae, Lacistermaceae, Empetraceae, Ceratophylleae.

Class 2: Gymnospermae : 3 families.

Families: Gnetaceae, Coniferae, Cycadaceae.

Class 3: Monocotyledons (A - G) : 7 series.

Series A: Microspermae : 3 families

Families: Hydrocharideae, Burmanniaceae, Orchideae.

Series B: Epigynae : 7 families.

Families: Scitamineae, Bromeliaceae, Haemodoraceae, Irideae, Amaryllideae, Taccaceae, Dioscoreaceae.

Series C: Coronarieae : 8 families

Families: Roxburghiaceae, Liliaceae, Pontederiaceae, Philydraceae, Xyrideae, Mayaceae, Commelinaceae, Rapateaceae.

Series D: Calycinae: 3 families

Families: Flagellarieae, Juncaceae, Palmae.

Series E: Nudiflorae : 5 families

Families: Pandanaceae, Cyclanthaceae, Typhaceae, Aroideae, Lemnaceae.

Series F: Apocarpeae : 3 families

Families: Triurideae, Alismaceae, Naidaceae.

Series G: Glumaceae : 5 families

Families: Eriocauleae, Centrolepideae, Restiaceae, Cyperaceae, Gramineae.

4.3.1 Characteristics of Bentham & Hooker

Emryo with two cotyledons: stem with open vascular bundles; leaves netted (reticulate) venation; flowers usually pentamerous,……………………………………… *Class*: *Dicotyledons*

Embryo with a single cotyledon: stem with vascular closed bundles; leaves with parallel venation; flowers usually trimerous………………………………………. *Class*: *Monocotyledons*

Class Dicotyledons

Sub-class I Flowers usually with two whorls of perianth i.e. (calyx and corolla). Petals free...*Polypetalae*

Sub-class II Flowers usually with two whorls of perianth i.e. (calyx and corolla). Petals united...*Gamopetalae*

Sub-class III Flowers usually with one whorl of perianth. commonly sepaloid or absent.. *Monochlamydeae*

Sub-Class I — Polypetalae

Series (i): Petals and stamens hypogynous. disc absent!.................. *Thalamiflorae*

(1) Androecium rarely definite gynoecium free or immersed in toms, rarely united: embryo minute albuminous .... *Ranales*

(2) Gynoecium syncarpous, parietal placentation................................*Parietales*

(3) Gynoecium syncarpous. free central placentation: Herbs. sepals 5 or 4. petals 5 or 4 stamens twice petals. Obdiplostemonous ....*Caryophyllineae*

(4) Flowers rarely irregular; sepals 5, 2 or 4. free or united: petals as many or (0); stamens indefinite monadelphous; gynoecium 3 to indefinite numbers of carpels. carpels united ....*Malvales*

Series (*ii*) Stamens hypogynous. disc present, ovary superior ....*Disciflorae*

(1) Ovary superior or inferior, syncarpous; stamens twice the number of sepals, in two or one whorl: ....*Geraniales*

Series (*iii*) Flower perigynous or epigynous: ovary sometimes inferior: ovary enclosed by developments of floral axis. ....*Calyciflorae*

(1) Gynoecium one or more carpellary, apocarpous: flower actinomorphic or zygomorphic. Perigynous. ....*Rosales*

(2) Flower regular, usually bisexual: Ovary syncarpous. inferior: styles undivided or very rarely styles are free…....................................*Myrtales*

(3) Flowers bisexual or unisexual. parietal placentation. styles free or connate ... ……………………………………………………………………*Passiflorales*

(9) Flowers bisexual, locules in Ovary one to indefinite number. inflorescence umbel…..*Umbellales*

Sub-Class III - Gamopetalae

Series (i): Ovary inferior. stamens usually as many as petals..................*Inferae*

(1) Flowers regular or irregular, stamens epipetalous, ovary with 2 - indefinite number of locules. ……………………………………………….*Rubiales*

(2) Flowers regular or irregular, stamens epipetalous, ovary with one locule and one ovule; stamens, syngenesious ....*Asterales*

Series (ii) Ovary superior; stamens as many as petals or numerous, petals opposite or alternate to petals..*Heteromerae*

(1) Flowers regular, petals 4-5, stamens as many as the petals or numerous, inserted on receptacle……………………………….…….*Ericales*

(2) Flowers regular, petals 5, stamens 5 or numerous, ovary superior, herbaceous, prostrate or climbing plants …………………………………*Primulales*

(3) Flowers regular, petals 4-5, stamens as many as the petals, inserted on the corolla, ovary superior………..…………………………………*Ebenales*

Series (iii) Ovary usually superior; stamens as many as or fewer than corolla lobes. alternipetalous: gynoecium 2 rarely to 1-3-carpellary..…*Bicarpellatae*

(3) Flower regular, hypogynous; stamens epipetalous: leaves generally opposite. ………………………………………………………………….....*Gentianales*

(4) Flower regular, hypogynous; leaves alternate; stamens epipetalous; ovary 1-5 loculed.. *Polemonianles*

(5) Flowers usually irregular, corolla often bilipped; stamens generally fewer than corolla lobes. usually 4, didynamous or 2; ovary 1-4 locular, ovules usually indefinite... *Personales*

Indefinite number of ovules per loculus; sepals 5, fused; petals 3 + 2, gamopetalous; stamens 4 or 5, gynoecium bicarpellary. syncarpous.. ……………………………………………………………*Acanthaceae.*

(6) Corolla usually bilpped; flower hypogynous, rarely regular;

Ovary 2 - 4 loculed. ovules solitary in loculus or rarely more than one; first a drupe or nutlets.. *Lamiales*

Sub-class - Monochlamydeae

Flowers usually with one whorl of perianth commonly sepaloid or perianth absent.

Series A. Terrestrial plants with usually bisexual flowers; stamens generally equal in number to perianth lobes; ovules usually solitary; embryo curved or coiled in endosperm.. *Curvembryae*

Series B. Plants are many seeded submerged aquatica ….*Multiovulatae Aquaticae*

Series C. Plants are many seeded terrestrial …………*Multiovulatae Terrestres*.

Series D. Seeds are endospermous and with aminute embryo ….*Microembryeae*.

Series E. Ovary is monocarpellary and one ovuled ……………..*Daphnales*.

Series F. Ovary is one locular, inferior, no of ovules is 1 to 3.. *Achlamydosporeae*.

Series G. Flowers are unisexual, ovary is monocarpellary or syncarpous …………………………………………………………………..*Unisexuales*

Series H. Unisexual families of doubteful or unknown affinities ………………………………………………………………*Ordines Anomali*.

Class 2 : Gymnospermae

Class 3 : Monocotyledons

Series A. Ovary is inferior, seeds are minute ………………..*Microspermae*

Series B. Ovary is inferior, seeds are large and with a copiuns endosperms ………………………………………………………………… *Epigynae*

Series C. Perianth atleast the inner one is petatoid, the ovay is superior ……………………………………………………………………*Coronarieae*.

Series D. Perianth is sepaloid ovay is superior ………………………*Calycinae*.

Series E. Perianth is usually absent or reduced to minute scales, seeds are albuminous ……………………………………………………..*Nudifloreae*.

Series F. The perinath is about or uni-biseriate, ovary is superior with one or more than one tree coupels. Seeds albumiuoue ………………………*Apocarpeae*.

Series G. Perianth is scaly or glumaceous or about the ovary is usually one ovuled, seeds are alluminous.. *Glumaceae*.

4.3.2 Advantages and Disadvantages of Bentham & Hooker's Classification

Advantage is it provides easy means and ways of identifying plant.

Disadvantage are:

– Retention of Monochamydeae in which biseriate perianth as a rule in order.

– Family salicineae and cupuliferae are similar to now extinct.

– Simple flower to Paronychieae as elaborate primitive, thus Chenopodiaceae are apetalous allies of Caryophyllaceae.

– Position of Monochlamydeae and delimitation due to their affinities (Rendle)

– In Monocots greater emphasis on relative position of ovary, so Iridaceae, Amayllidaceae shows greater affinity to Liliaceae then Scitamineae and Bromelliaceae as common epigyuous character.

4.3.3 Key to the identification of the Families

(*a*) Flowers mostly penta or tetramerous

(*b*) Calyx and corolla mostly distinct.

(*a*) Flowers mostly trimerous

(*b*) Calyx and corolla mostly not distinguished as separate whorls; perianth present, Monocotyledons.

……………………………………………………………*Dicotyledons*

I. DICOTYLEDONS

(i) Corolla consisting of mostly free petals ………………….*Polypetalae*

(ii) Corolla consisting of mostly fused petals……… *Sympetatae* (Gamopetalae)

(i) Polypelatae

(A) Ovary Superior

1. Flowers unisexual…………………………………..*Euphorbiaceae*

2. Gynoecium apocarpous, fruit never drupe. calyx and corolla sometimes not distinguished. ………………………………………..*Ranunculaceae*

3. Gynoecium either apocarpous or monocarpellary, fruit may be a drupe. epicalyx often present. …………………………………….*Rosaceae*

4. Gynoecium monocarpellary

(a) Fruit drupe. …………………………………………… *Rosaceae*

(b) Fruit legume or lomentum

(i) Flowers actinomorphic, stamens mostly indefinite …………………………………………….*Mimosoideae*

(ii) Flowers zygomorphic, aestivation of the corolla ascending imbricate; stamens 10 but never diadelphous………………………………*Caesalpinoideae*

(iii) Flowers zygomorphic, aestivation of the corolla descending imbricate, stamens ten, diadelphous,................*Papilionatae*

5. Gynoecium syncarpous

(a) Placentation free-central ………………………..…*Caryophyllaceae*

(b) Placentation parietal

(i) Gynoeceum tricarpellary ……………………….……..*Violaceae*

(ii) K2 or 3 C 2 + 2 or 3 + 3 A□ G (2 – □)……………..*Papaveraceae*

(iv) K2 + 2 C4 A2 + 4 (tetradynamous). G(2) ……………*Cruciferae*

(c) Placentation axile .

(i) Epicalyx present, stamens monadelphous …………*Malvaceae*

(ii) Prominent disc present below gynoecium, stamens obdiplostemonous or polyadelphous. ……………………………………..….*Rutaceae*

(d) *Ovary inferior:*

(i) Leaves exstipulate, inflorescence umbel …………..…*Umbelliferae*

(ii) Leaves exstipulate, inflorescence mostly cymose or a spike, petals often nearly circular, stamens indefinite…………………………………………..….... *Myrtaceae*

(iii) Leaves mostly stipulate, the latter often adnate to the petals, never circular: epicalyx often present ……………………………………………………………...*Rosaceae*

(ii) Sympetalae (Gamopetalae)

(A) Ovary superior:

(a) Corolla actinomorphic

(i) Stamens often included in the corolla tube, anthers mostly sagittate and convinient round the stigmatic head, stigma dumble-shaped ……………………………………………………………..*Apocynacease*

(ii) Gynostegium present, gynoecium free below and fused above …………………………………………………....*Asclepiadaceae*

(iii) Ovary bilocular with typically two ovules in each loculus. …………………………………………………..*Convolvulaceae*

(iv) Carpels obliquely placed in the flower, ovary bilocular, placenta swollen, ovules shining and indefinite. ……………………*Solanaceae*

(b) Corolla zygomorphic

(i) Corolla mostly bilabiate, style gynobasic. …………………*Labiatae*

(ii) Corolla often bilabiate, ovary elongated, style long and terminal. ……………………………………………………….*Acanthaceae*

(B) Ovary inferior

(i) Mostly climbing plants with well developed tendrils, flowers unisexual, androecium complex, anthers twisted. …………………*Cucurbitaceae*

(ii) Inflorescence capitulum, calyx in the form of pappus, anthers cohering by their edges (syngenesious), placentation basal. ……….*Compositae*

(iii) Stipules prominent, either inter or intrapetiolar, placentation axile. ………………………………………………………*Rubiaceae*

II. MONOCOTYLEDONS:

(i) Gynoecium monocarpellary with two feathery stigmas, perianth absent, ovary superior ……………………………………………*Gramineae*

(ii) Flowers unisexual, minute and produced in very large numbers, ovary superior. …………………………………………………*Palmaee*

(iii) Flowers bisexual, six stamens in two whorls, ovary superior.. *Liliaceae*

(iv) Flowers mostly bisexual, stamens five in two whorls, ovary inferior …………………………………………………………..M*usaceae*

4.4 NOMENCLATURE

Name is the means of reference to all living and non-living things. Any object known to human being is given a name to describe and communicate ideas about it. The name may be different in different languages and at different places. The art of naming the object is known as nomenclature and when it comes to naming of plants it is called botanical nomenclature.

The process of naming plants based on international rules proposed by botanists to ensure a stable and universal uniform system is called botanical nomenclature.

Common Names

Common name is the name of the plant in a particular area or locality given by the people of that particular area. Such names vary from place to place and language to language. In India the name changes with the dialect.

Scientific Name

Scientists suggested name in such a way that it is accepted in the world and is used internationally. But again, the problem remains the same, *i.e.*, the language which is not universal. So the botanists agreed to lay down certain rules and conditions. The main suggestion was that the language of the name should be in Latin. Botanical Latin is an international language used by botanists the world over for naming and describing plants. It originates from the Latin of the Roman plant writers, notably Pliny the Elder (A.D. 23-79). The Swedish botanist Carolus Linnaeus (1707-79) formally established the tradition that all plants should be given Latin names (or names of Latin form) and that works relating to them should also be in Latin. It is because:

1. Latin is a dead language, so the meanings of words do not change in the same way as those for living languages.
2. Botanical, Latin is very descriptive, with many terms for shape, texture and colour.

3. Latin does not inspire the political jealousies that might emerge if botanists were to convert to, say, English or Spanish.

During 1600 to 1850 AD Europe, particularly Greece, had dominated the world of science. The language was Latin but the script was Roman.

Binomial Nomenclature

Linnaeus for the first time proposed that every living being has a binomial name, *i.e.*, a name with two epithets. One is generic and the other is specific epithet. If an organism has a variety also, then the name becomes trinomial. Linnaeus proposed some rules for generic names of plants in Fundamental Botanica (1736) and Critica Botanica (1737). A.P.de Candolle for the first time proposed rules for nomenclature of plants which were passed by International Botanical Congress at Paris (1867). Swedish Naturalist Carolus Linnaeus who started naming plants in 1753 as Binomial names. It was published in his book "Species Plantarum".

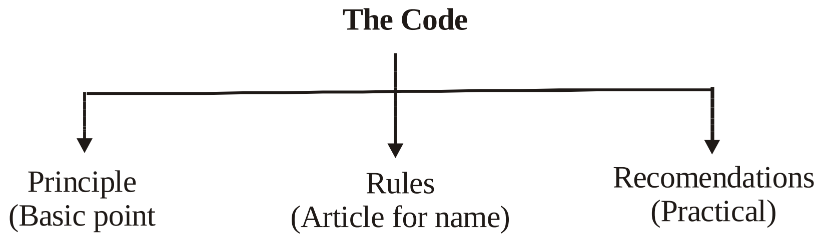
The generic name is always a noun showing colour, name or adjective, *e.g.*, *Sarracenia* named after a scientist Michel Sarracin. Species is always an adjective, *e.g.*, for white flower, it is alba., for edible one it is sativa, black colour-nigrum etc.These names are not used always. Species may be a Pronoun, *e.g.*, *americana, indica, benghalensis,* etc. It may be shape of a leaf (character of plant), *e.g.*, *sagittifolia*, name of other scientist to whom the plant is dedicated, *e.g.*, *Sahnii* etc.

4.4.1 International code for nomenclature of Algae, Fungi and Plants (ICN)

At the middle of 18th century, plant names were generally polynomial consisting of several words in a series. Linnaeus proposed the elementary rules in Philosophia Botanica in 1751. In 1813 A.P.de Candolle proposed details of the rules regarding plant nomenclature in *Theorie elementaire de la botanique*. Alphonse de Candolle son of A.P. de Candolle convened an assembly of botanists of the world to present a new set of rules. Candolle convened the first International Botanical Congress at Paris in 1867. The *International Code for Nomenclature of Algae, Fungi and Plants (ICN)* passed by Melbourne Congress was earlier known as *International code Botanical Nomenclature (ICBN).*

Presently, the rules and recommendations of Vienna code which were proposed by J. McNeill et al in 2005 are in practice.

The present International Code of Botanical Nomenclature (Lanjouw, 1956) is the result of many years of trial and error. 1956 edition of the code gives detailed instructions on the steps to be taken when any change appears necessary. It is interesting to note that during the last three or four International Botanical Congresses there have been, but few changes, except perhaps in the rearrangement of the code and in some less important points of nomenclature. The ICBN is based on Linne's own 'Philosophia Botanica', when he lays down the main points of nomenclature in the form of aphorisms (principles). The code is divided into three clear parts, principles, rules and recommendations. In addition there are a few interesting appendices. The principles are basic points on which the code is based. They do not give detailed rules about nomenclature, but show the main ideas that have guided the compilers of the code, and should be kept in view by any botanist attempting to publish a new taxon.



4.4.2 Focal Points of ICN (2011)

1. Plants require a precise and simple system of nomenclature used by Botanists in all countries, dealing, on the one hand, with the terms which denote the ranks of taxonomic groups or units, and on the other hand with the scientific names which are applied to the individual taxonomic groups of plants. The purpose of giving a name to a taxonomic group is not to indicate its character or history, but to supply a means of referring it and to indicate its taxonomic rank. The code aims at the provision of a stable method of naming taxonomic groups, avoiding and rejecting the use of names which may cause error or ambiguity or throw science into confusion. It avoids the useless creation of names.
2. The Principles form the basis of the system of Botanical Nomenclature.
3. The detailed provisions are divided into Rules and Recommendations. Examples are added to the rules and the recommendations to illustrate them.
4. The object of the Rules is to put the nomenclature of the past into order and to provide for the future; names contrary to a rule cannot be maintained.
5. The Recommendations deal with subsidiary points, their object being to bring about greater uniformity and clearness, especially in future nomenclature, names contrary to a recommendation cannot, on that account, be rejected, but they are not examples to be followed.
6. The provisions regulate the modification of this code from its last decisions.
7. The Rules and Recommendations apply to all organisms treated as plants (except Bacteria), whether fossil or non-fossil. Special provisions are needed for certain groups

of plants. The International Code of Nomenclature of cultivated plants (1980) was adopted by the International Commission for the Nomenclature of Cultivated Plants.

8. The only proper reasons for changing a name are either a more profound knowledge of the facts resulting from adequate taxonomic study or the necessity of giving up nomenclature that is contrary to the rules.
9. In the absence of a relevant rule or where the consequences of rules are doubtful, established custom is followed.
10. This edition of the code supersedes all previous editions.

4.4.3 Important Rules and Recommendations

1. All those plants which belong to one genus must be designated by the source generic name (Rule 213)
2. All those plants which belong to different genera must be designated by different generic names (Rule 214)
3. He who establishes a new genus should give it a name (Rule 218)
4. Those generic names are best which show essential characters of plants or its appearance (Rule 240)
5. Generic names one and a half foot long or difficult to pronounce or unpleasant are to be avoided (Rule 249)
6. The specific name must distinguish a plant from all its relatives (Rule 257)
7. Size does not distinguish species (Rule 260)
8. The original place of plant does not give specific difference (Rule 264)
9. A generic name must be applied to each species (Rule 284)
10. The specific name should always follow the generic name (Rule 285)

4.4.4 Principles

There are six principles-

I. Botanical nomenclature is independent of zoological nomenclature. The code applies equally to names of taxonomic groups treated as plants whether or not these groups were originally so treated (Plants do not include Bacteria).

II. Application of names of taxonomic groups is determined by means of nomenclature types.

III. The nomenclature of a taxonomic group is based upon priority of publication.

IV. Each taxonomic group with a particular circumscription, position, and rank can bear only one correct name, the earliest that is in accordance with the rules, except in specific cases.

V. Scientific names of taxonomic groups are treated as Latin regardless of their derivation.

VI. The rules of nomenclature are retroactive unless expressly limited.

According to the code, every taxon or group of plants can bear only one correct name and vice versa a name can be applied to one group of plants. The rules or articles give detailed prescriptions on all the points connected with the naming of the plants. The recommendations are practical application of the rules.

4.4.5 Rules

4.4.5.1 Rank of Taxa

Every individual plant when placed in classification, the species is the basic unit of classification. Each species belongs to a series of taxa of consecutively higher rank. In article 3 “the principal ranks of taxa in ascending sequence are species, genus, family, order, class, division and kingdom. This code defines the categories only by listing their sequence. This may not be true for small order, family, or genus but the sequence must not be changed

Categories such as family (ending with- aceae, Polygonaceae) suborder (ending with ineae, Chenopodineae), order (ending with- ales, Malvales) and so on may be used. In other words, the code provides standardized grammatical endings for the categories from division down to subtribe. The ending with- aceae are used basing on its generic names e.g. Poa, Poaceae, Aster, Asteraceae etc. oideae- subfamily, -eae tribe and -inae subtribe.

A unique exception to article 52 of the code is the name Leguminosae is sanctioned only as long as it includes all three subfamilies Papilionoideae, Caesalpinoideae and Mimosoideae. If the subfamilies are upgraded to family status the Papilionaceae shall be called Fabaceae.

Types of Taxon

Names of different taxonomic groups are based on the type method. A type is that constituent element of a taxon to which the name of the taxon is permanently attached. According to Principle II “the application of name of taxonomic groups is determined by means of nomenclatural types”. This means that when a species is described as new, the author must indicate type of specimen on which the new species is based. In the case of species or infra-specific names, the type is an individual specimen, which is the type specimen on which the new species is based.

(a) **Holotype:** Single specimen, may be whole plant or a part of it with which the name of taxon is permanently attached, is known as holotype.

(b) **Isotype:** An isotype is a biological specimen duplicate of the holotype collected in the same place and at the same time (in the type locality).

(c) **Paratype:** A paratype is any of one or more biological specimen other than the holotype listed as representative and used for the development of the original description of a species or subspecies.

(d) **Syntype:** The specimen which is the basis of new taxon when no holotype is designated by author is known as syntype. If author studies collection from different localities and by different collectors and decides to establish a new species, labels all of them as types, all these specimen become syntypes.

(e) **Lectotype:** It is type chosen to serve as Holotype, when either an earlier designated holotype was lost or destroyed or holotype was never designated and from the isotype, paratype or syntype a specimen is chosen by a specialist to serve as the type.

(f) **Neotype:** If holotpe, isotype, paratype or syntype are lost or not available a Neotype is selected from other specimens, to serve as Type. Some taxonomists call it Standard Specimen.

(g) **Topotype:** When no original type material is available and a specimen is collected from type locality is chosen to serve as type it is called Topotype.

It is also felt that a species might be undergoing some natural adaptation and variations in course of time and also in space. Type has served in valuable purpose in correct identification of specimens. It is also agreed that a preserved specimen is always a better representation of any taxonomic group than a description or illustration.

4.4.5.2 Principle of Priority

Principle of Priority is concerned with the selection of a single correct name of taxonomic group. Only legitimate names should be retained while the illegitimate names should be rejected. According to article 11-12 rules for priority are:

(i) Each family or taxon of lower rank with a particular circumscription, position and rank can bear only one correct name (Art 11).

(ii) For any taxon from family to genus, the correct name is the earliest legitimate one, validly published with the same rank (Art -11).

(iii) A name of a taxon has no status under this code unless it is validly published (Art-12).

(iv) The application of both conserved and rejected names is determined by nomenclatural type (Art-14).

(v) "When a name proposed for conservation has been provisionally approved by the general committee, botanists are authorized to retain it pending the decision of a later international Botanical Congress".

Valid Publication of names is usually considered beginning in May 1753, the date of publication of *Species Plantarum* vol. I by Linnaeus.

With many names of a taxon, the valid will be the earliest name which is regarded as correct name. Rule of Priority provides stability to this name.

The principle that seniority is fixed by the date of valid publication is known as Principle of Priority.

4.4.5.3 Limitations of the Principle of Priority

1. **Starting dates:** Principle of Priority starts with the *Species Plantarum* of Linnaeus published on 1-5-1753.
2. **Limited only up to family ranks:** This principle does not apply over family rank.
3. The correct name should not be outside the rank. Only when a correct name in the taxon is not available, a combination with other rank is allowed.
4. The application of Principle of Priority resulted in numerous name changes. To avoid it a list of conserved generic and family names has been prepared and published in the code with some changes. Such Nomina conservanda *(nom. Cons.)* are to be used as correct name replacing earlier legitimate names, e.g., *Sesbania scop,* 1777 is the conserved genus as against *Sesban adam* 1763 and *Agati adam* 1763.

4.4.5.4 Effective and Valid Publication

The name is effectively published when the published name should appear in printed from and distributed to the botanical institutions. The name is valid when the name is published in accordance with the provisions of the code.

A validly published name is one which has been (1) effectively published (2) accompanied by description of the taxon or by client or by direct or indirect reference to a previously and effectively published description of it. Effective publication of a name deals with the mechanisms of its distribution, valid publication deals with both distribution of the name and with the preparation of the textual matter prior to distribution.

4.4.5.5 Publication of Names

The name of a Taxon should fulfil certain requirements before its effective publication as:

(*i*) **Formulation:** It should indicate

- (*a*) *sp. nov.* (species novum) for a new species
- (*b*) *Comb. nov.* (combination novum) for change in the epithet of basionym. The name of the original author should be kept in Parantheses.
- (*c*) *nom. nov.* (Nomen novum) when the original name is completely replaced.

(*ii*) **English or Latin diagnosis: -** As per ICN **(**The Melbourne Code) the requirement of Latin diagnosis for Names of New Taxa has been changed. As per this code the description of new names should be in English or Latin.

(*iii*) **Typification: -** Holotype should be designated. The name of new Taxon is valid only when the type of the name is mentioned after January 1, 1990. The name of the taxon whose type is a specimen or unpublished illustration; the herbarium or institution in which the type is conserved must be specified.

(*iv*) After January 1, 1996 the name of new taxon of fossil should be accompanied by a Latin or English description of character.

4.4.5.6 Citation of Author's Name

A name cannot be complete without an author's name. The author's name is abbreviated, *e.g,* Linneaus is Abbreviated as Linn or L., Bentham as Benth.; Hooker as Hook.., Roxburgh as Roxb, Lamarck as Lamk. etc.

According to Article 46 the indication of name of a taxon are to be accurate and complete. It is necessary to cite the name of the author who first validly published the name. If the author's name is too long it should be abbreviated. *e.g., Hibiscus* L., *lndigofera grandulosa* var. *Syskessi* Baker, *Solanum nigrum* Linn etc.

4.4.5.7 Retention, Choice and Rejection of Names

When a genus is divided into two or more genera or a species is split into two or more species, the original generic or specific name must be retained for the new taxon containing the type, this applies also to infra-specific taxa.

When a section of a genus or species is transferred to another genus or species without alternation in rank, the original name must be retained whenever possible.

When the rank of a genus or infra generic taxon is changed, the correct name of epithet is the earliest legitimate one available in the new rank.

When taxa of the same rank are united into the same rank or are united into one, the oldest legitimate name must be used for the new combined taxon, if the names are of same date, the author who first unites them has a right to choose one of the names and his choice must be followed by subsequent botanists.

A name or epithet must not be rejected merely because it is badly chosen or disagreable. The name must be rejected when it is illegitimate and superfluous when published or homonym or tautonym.

The authors have full liberty to coin their names but in Latin or Latinized form of other words; names of genera and higher taxa are written with a capital initial letter. Specific names should start with a small letter.

4.4.5.8 Rejection of Names

a) A name is rejected if name is illegitimate:

   i) Nomenclature superfluous

   ii) If published in contravention of specific rules (duplicate/invalidly published)

   iii) If it is rejected generic name.

   iv) If tautonym.

b) If owing to its use with different meaning source of confusion.

   e.g. *Quercus rubra* L. American oak.

   Quercus falcata Michx. Spanish oak.

   Quercus borealis Michx. f. Red oak.

   Reder proposed that *Quercus rubra* L. as nomen ambiqua and rejected *Quercus falcata* and *Quercus borealis* as valid name.

c). name of taxon must be rejected if the characters derived from 2 or more entirely discordant element, unless it is possible to select one of these element as site factory type of the name.

   e.g. *Actinotinus* established by Oliver 1888 a specimen derived from *Viburnum* and *Aesculus* rejected.

   The rules for rejection of names are

(i) ***Nomen nudunm (nom. nud):*** Name without description, without typification and Latin diagnosis etc is rejected.

(ii) **Tautonym:** Botanical nomenclature does not allow tautonym (repetition of generic name), *e.g., Malus malus.* Repetition of specific epithet in infra specific epithet does not constitute tautonym.

(iii) **Later homonym:** If a name which already exists is given to other taxa once again then the later homonym is rejected.

(iv) **Nomen *ambiguum* (nom. ambig):** The name is rejected in different sense by different authors.

(v) ***Nomen confusum (nom. confus):*** The name should not be confusing.

(vi) ***Nomen dubium (non. dub):*** Dubious name, *i.e.,* with uncertain application is also rejected.

4.4.5.9 Names of Cultivated Plants

The name of the cultivar is not analogous to the botanical variety and according to ICNCP the names are written with a capital letter preceded by abbreviation CV or placed in a single inverted comma. The name may be used after generic, specific or common names e.g. *Citrullus lanatus* CV Sugar baby. *Camelia japonica* CV. Purple Dawn etc.

It is recommended that cultivar names be registered with a recognised registration authority which undertakes to keep a list of cultivars for plants concerned. Registration is a precaution against duplication, misuse or fraudulent usage of cultivar names.

4.4.5.10 Names of Hybrids in Cultivation

The names of hybrids may follow the pattern of monohybrid crosses of Mendle between the species may be connected by multiplication sign (X). Again the name of the plant may be used in Latin for *Salix aurita* X *Salix caprea*, *Agrotis* X *Polypogon* X *Andropogon* etc.

4.5 HERBARIUM

Herbarium is a collection of pressed and dried plant specimens mounted on appropriate sheets, arranged according to some known system of classification and kept in pigeon holes of steel or wooden cupboards usually specially prepared for this purpose. There are thousands of plants in the universe and it is not possible to identify them without assigning them in a definite system. This was the beginning of the systematic botany and arrangement of plants in definite system is one of the steps of the process. Before arranging them it is necessary to collect plants according to certain system. The collected plant is the plant specimen and the specimens are the prime sources for floristic studies. Plant materials must be carefully selected, collected and preserved in such a way that they provide a clue for identification and later arranged accurately for classification. The preserved specimen becomes a permanent record for investigation. This is herbarium specimen.

Steps for Herbarium Preparation

- Collection of specimen
- Drying of specimen
- Preservation of specimen
- Mounting of the specimen
- Labeling of the specimen
- Filing of the specimen

Collection - Drying - Preservation - Mounting - Labeling – Filing

4.5.1 Functions of Herbarium

A modern Herbarium serves valuable functions or utility. The following are few important functions of a herbarium are:

1. It provides necessary information for verifying and identifying newly collected plants.
2. It is an invaluable conservatory of plant material and data.
3. It is storehouse of collections including the valuable type specimens. The herbaria greatly aid in all kinds of taxonomic researches.
4. Serves as a fundamental resource for identification of all plants of the world.
5. It serves as a source for collection of biodiversity. Most estimates on global biodiversity today are based on herbarium collection only.
6. It aids in biodiversity monitoring by carrying out security of herbarium collection to obtain quantitative baseline data on the distribution and abundance of keystone species is essential for all monitoring programmes.
7. It serves as a repository of voucher specimens on which various botanical researches are carried out.
8. Aids in assessment of conservation status of a taxon.
9. Vast collection of a particular species in a herbarium aids in assessing the diversity or variations exhibited by a species in its distributional range helping in population biology studies.
10. It serves as a source for search of new genetic material for improvement of cultivated stock.
11. It helps in development of computer database on plants and maintains active links to international networks of systematic resources and electronic database.

12. It provides research facilities to the students of taxonomic research.
13. It provides complete idea of vegetation and place of origin of plants.
14. The ecological, economical and ethnobotanical data may be obtained, and
15. It provides key for the preparation of modern system of classification.

4.5.2 Important Herbaria of India and World

S.NO	Name of Herbarium Places	No. of plants	Year of Specimens founding	Abbreviation
1	Central National Herbarium, Calcutta	2,500,00	1793	CAL
2	Forest Research Institute, Dehradun	3,000,00	1816	DD
3	Herbarium of the National Botanic Garden, Lucknow	1,00,000	1984	NBG
4	Botanical Survey of India, Dehradun Northern circle	60,000	1956	BSD

Important World's Herbaria

1	New York Botanical Garden	7,200,000	USA
2	Royal Botanic Gardens Kew	7,000,000	UK; Kew, England
3	Missouri Botanical Garden	5,870,000	USA; St. Louis, Missouri
4	British Museum of Natural History	5,200,000	UK; London, England

4.6 BOTANICAL GARDEN

Botanical gardens or botanic gardens are generally well-tended parks displaying a wide range of plants labeled with their botanical names. They may contain specialist plant collections such as orchids, cacti and succulent plants. Botanic gardens and arboretums are primarily outdoor collections of labeled living plants, the entire structure being systematically and beautifully landscape and playing passive role in their communities. They are the basic source of plants and information about plants to people who have made gardening their hobby. They are the basic source of new information concerning a large number of plants. They exhibit the native vegetation of their region and sometimes also act as "outdoor laboratories" for students and researchers. They provide beauty to the institution to which they belong some botanic gardens are large enough for a pleasing drive through them all the blossom time and act as a serene site of relaxation, Some gardens have special exhibits such as hedge displays or are made up of smaller gardens to be chosen for our own kitchen gardens, From them we learn what plants and in what combinations we may have them in our little home gardens to give a good design, In several public or government gardens there are regular well-organized popular courses for public, and people can learn both theoretically and practically about gardens, especially house plants, home landscaping, flower arrangement Christmas decoration.

A modern botanical or botanic garden should display, the following:

(1) Collections of different varieties of cultivated plants especially ornamental ones such as roses, peonies dahlias, poppies, cannas, lilies, primulas, violas, crotons, coleus, ferns, palms, orchids etc,

(2) Medicinal plants, plants of economic value, and plants of special interest.

(3) Plants of certain geographic formations, such as desert plants alpine plants, marsh plants, aquatic plants etc.

(4) Weeds and methods of their control.

(5) Plants mentioned in classical and religious literature, state f1owers, national flowers and favourate flowers of the locality

4.6.1 FUNCTIONS OF BOTANIC GARDEN

1. Provide basis for modern taxonomic studies, such as for comparison of morphological characters in the preserved and living specimens.
2. Provide adequate facilities for plant introduction and acclimatization work and thus are an important tool for promotion of economic plants.
3. Germplasm collections in botanical gardens act as basic material for hybridisation and improvement.
4. Botanical gardens, with their elaborate facilities of glass houses, green houses (and in some even phytotrons) provide shelter to many rare and endangered plant species of the world, which for various reasons are facing danger of extinction in their natural habitat. Thus gardens also help in conservation of the world flora.
5. Material for study and research for those plants which will not otherwise be available in that place or region.
6. Provides facilities for training in landscape, gardening, horticultural operations and other allied discipline.

7. Well established botanic gardens maintain exchange relations with other gardens of the world and thus distribute seeds, saplings and other propagules to far off places, some botanic gardens also bring out at regular intervals, lists of plants available for distribution and exchange. The term '*Index Seminum*' is often applied to such lists of seeds offered for exchange.
8. Botanic gardens remain important for their records of local flora and as basis for continued monographic work. According to Holttum (1970), it is essential basis for all other studies of plants. The gardens also provide facilities for collection of living plant material for bio systematic studies. Many of these gardens supply seeds and material for botanical investigation. Supply of seeds has been listed by Haywood (1964). The green houses, herbaria, library and research laboratory. The IABG (International Association of Botanic Gardens) was established in 1962. At present there are over 125 botanic gardens with such documented collections. This association has published the International Directory of Botanic Gardens (1963).
9. Botanic gardens are centers of recreation and aesthetic beauty.

4.6.2 SPECIAL KINDS OR SECTIONS OF GARDENS

a. **Arboretum (Arboreta)**
b. **Pinetum (Pineta)**
c. **Orchidarium (Orchidaria)**
d. **Bambusetum (Bambuseta)**

A useful database cataloging of the world's botanic gardens can also be found at the Botanic Gardens Conservation International (BGCI) website. With over 800 participating botanical gardens, BGCI forms the world's largest network for plant conservation and environmental education.

4.6.3 IMPORTANT BOTANIC GARDENS OF THE WORLD

Royal Botanic Gardens, Kew, England

In England, the famous Royal Botanic Gardens at Kew started as the private garden of Sir Henry Capel an enthusiastic horticulturist who died in 1696.

Arthur William Hill (Knighted in 1931), Sir Geoffrey Evans, Edward James Salisbury (Knighted in 1946) served the Kew Gardens as Directors. George Taylor is the present director of Kew. The present area of the Royal Botanic Gardens, Kew is about 300 acres and they are now under the Ministry of Agriculture, Fisheries and Food; although the Director has a wide degree of autonomy.

Missouri Botanical Garden, St. Louis, Missouri, USA

The Missouri Botanical Garden is a botanical garden located in St. Louis, Missouri. It is also known informally as Shaw's Garden for founder Henry Shaw, a botanist and philanthropist. Founded in 1859, the Missouri Botanical Garden is one of the oldest botanical institutions in the United States and a National Historic Landmark.

Botanical Garden of Curitiba Southern Brazil

The Jardim Botânico de Curitiba, in Portuguese, or the Botanical Garden of Curitiba, in English, is also known as the "Jardim Botânico Fanchette Rischbieter". This is a park located in the city of Curitiba, the capital of the state of Paraná, and the biggest city in southern Brazil. Opened in 1991.

Royal Botanic Gardens, Sydney

The Royal Botanic Gardens in Sydney, Australia, are the most central of the three major botanical gardens open to the public in Sydney. (The others are the Mount Annan Botanic Garden and the Mount Tomah Botanic Garden.) The Botanic Gardens were founded on this site by Governor Macquarie in 1816 as part of the Governor's Domain.

Royal Botanic Garden Edinburgh, Scotland

The Edinburgh botanic garden was founded in 1670 at St. Anne's Yard, near Holyrood Palace, by Dr. Robert Sibbald and Dr. Andrew Balfour. Nearly 36,000 plants are grown at the Botanics in Edinburgh or its three smaller satellite gardens located in other parts of Scotland.

Kirstenbosch National Botanical Garden, South Africa

Kirstenbosch is the name of a famous botanical garden nestled at the foot of Table Mountain in Cape Town. The garden is one of eight National Botanical Gardens covering five of South Africa's six different biomes.

Beijing Botanical Garden, China

The Beijing Botanical Garden is a botanical garden situated in the northwestern outskirts of Beijing, China between Xiangshan (Fragrant Hills) Park and Jade Spring Mountain in the Western Hills. The Beijing Botanical Garden was established in 1955.

Saint Petersburg Botanical Garden, Russia

The Saint Petersburg Botanical Garden, also known as the Botanic Gardens of the Komarov Botanical Institute or the Komarov Botanical Garden, is the oldest botanical garden in Russia.

Singapore Botanic Gardens

Singapore Botanic Gardens is a 63.7-hectare (157-acre) botanical garden in Singapore. It is half the size of the Royal Botanic Gardens in Kew or around one-fifth the size of Central

Park in New York. It is the only botanic garden in the world that opens from 5 a.m. to 12 midnight every single day of the year.

4.6.4 BOTANICAL GARDENS IN INDIA

In India there are many Botanical Gardens that include many plants and trees. The Botanical Gardens preserve many indigenous plant species as well as many exotic examples of floral species. The Botanical gardens are places for research regarding plantation, cultivation and quality and quantity of fruits and flowers. It also organizes regular flower show.

National Botanic Gardens, Lucknow, India

The site of the National Botanic Gardens is popularly known to the public of Lucknow as Sikander Bagh. There is an old garden situated at the south-eastern corner of the present National Botanic Gardens. It was built by Nawab Saadat Ali Khan (1789-1814). The present National Botanic Gardens with K.N. Kaul as its director is spread over about 75 acres on the south bank of the river Gomti.

Acharya J. C. Bose Botanical Garden, Howrah

Indian Botanic Garden is established in 1787 by Lieutenant Colonel Robert Kyd, this garden is situated on the west bank of the river Hooghly (Ganga). The garden covers an area of 273 acres. Its unique landscape design initiated by Sir George King in 1872 is considered to be one of the best in the botanic gardens of the world with undulated land surfaces, artificial lakes and moats interconnected with underground pipes receiving water from the river Hooghly.

The garden was known as East India Company’s Garden or the ‘Company Bagan’ or Calcutta Garden and later as the Royal Botanic Garden which after independence was renamed as the ‘Indian Botanic Garden’ in 1950. It came under the management of the Botanical Survey of India on January 1, 1963. Over 12,000 trees and shrubs belonging to 1400 species together with thousands of herbaceous plants are in cultivation in the open in 25 Divisions, Glass houses, Green Houses and conservatories. The garden maintains the germplasm collection of Bamboos, *Bougainvillea, Citrus, Jasmine, Pandanus, Water Lilies* and has the richest collection of Palms (about 109 species) in whole of South East Asia. In addition succulents, *Hibiscus, Ficus,* Aromatic plants, Gymnosperms (in two Pinetums), Creepers, Ferns and a number of floricultural and arboricultural plants are grown in its Flower Garden, National Orchidarium, Student Garden. Besides a large number of medicinal plants in its Medicinal Plant Garden named as ‘Charak Udyan’ enrich the garden. A few interesting plants of the garden worth to mention are Branched Palm, Bread Fruit Tree, Double Coconut, Giant Water Lilies, Krishnabot , Mad tree, Shivalinga tree, etc. In addition researches are also conducted on plant introduction, multiplication, horticultural aspects and conservation. The Great Banyan Tree (*Ficus bengalensis* L.) of the Indian Botanic Garden attracts millions of visitors every year. It looks like a miniature forest and is over 250 years old with 2800 prop roots covering an area of 1.5 hectares. The large palm house of this garden has several interesting plants including the Double Coconut *(Lodoicea maldivica)* which produces the largest known seeds in the whole plant kingdom.

Lloyd's Botanical Garden

Lloyd's Botanical Garden is a 'one of its kinds' botanical garden in the Darjeeling city of West Bengal. In 1878 William Lloyd donated a piece of beautiful land with an area about 40 acres which was developed as a branch establishment of the Royal Botanic Garden Calcutta.

4.7 SUMMARY

Plant taxonomy is one of the earliest disciplines of Botany. Simpson (1961) suggested that systematics includes identification, taxonomy, classification and nomenclature. Classification denotes the arrangement of single plant or group of plants in distinct category following a system of nomenclature and in accordance with a particular and well established plan. The basic unit of classification is species. The various classifications of plants proposed so far, belong to artificial, natural and phylogenetic systems. Initially classification of plants was based on own principles. Natural system proposed by Bentham and Hooker in *Genera Plantarums* (1862-1883) which is based on free and fused petals was discussed in details. Advantages and disadvantages of Bentham & Hooker's classification have also been provided.

The process of naming plants on international rule proposed by botanists to ensure a stable and universal uniform is called botanical nomenclature. In this unit common name, scientific names, binomial nomenclature, different codes of ICBN (e.g. Paris code 1067 to Vienna code 2005) were also discussed. The principles (6), focal points of ICBN 1983, phylocode, The rules, rank of taxa, principle of priority, effective and valid publication, publications of names, citation of authors names, retention, choice and rejection of names, rejection of name, name of cultivated plants and names of hybrids in cultivation were discussed in detail.

4.8 GLOSSARY

Aims of taxonomy: Identification, nomenclature and classification
Alpha taxonomy: taxonomy of description and designation of species.
Artificial: system with the help of few characters with a intention of easy identification.
Beta taxonomy: arrangement of species in hierarchical manner.
Binomial: A name with two epithels (one generic and another specific)
Classification: arrangement of a single plant or group of plants in distinct category following a system of nomenclature with a particular and in accordance and well established plan.
Gamma taxonomy: taxonomy with intraspecific population and with phylogenetic trends.
Gamopetalae: fused petals
ICBN: International Code of Botanical Nomenclature.
ICNCP: International Code for Nomenclature of Cultivated Plants
Nature: system based on form relationships.
Omega taxonomy: perfect system based on available characters.
Phylocode: proposed to promote clear communication and efficient storage and retrieval of biological information.
Phylogenetic: System based on genetic relationship and evolution.
Polypetalae: free petals
Scientific name: name of plan accepted to the world and used internationally.
Sp. Nov (species novum) for a new species
Species: a unit of classification.
Taxonomy: includes identification, taxonomy, classification and nomenclature.
Type: Name of the taxon is based on type.

4.9 REFERENCES

- Lawrence G.H.M. (1951). Taxonomy of Vascular plants Macmillan, New York.
- Mathur R.C. (1972). Systematic Botany Angiosperms, Agra Book Store, Agra.
- Gupta R.K. (1981). A Text Book of Systematic Botany, Atma Ram & Sons, Delhi
- Street H.E. (ed) (1978) Essay in Plant Taxonomy, AP London & New York.
- Stace C.A. (1989). The Plant Taxonomy and Biosystematics Edward Arnold, London.

4.10 SUGGESTED READINGS

- Angiosperms by Singh, Pande and Jain, Rastogi Publication. Meerut.
- Angisoperms by B.P. Pande, S. Chand & Co., Delhi.
- Chopra G.L. (1977). Angiosperms (Systematic and Life cycle), Nagin and Company, Delhi.
- Flowering Plants Angiosperms, Lalit M. Tewari & Jeewan S. Jalal (2011) Jagdamba Publishing Company, New Delhi.

4.11 TERMINAL QUESTIONS

1-Describe classification proposed by Bentham and Hooker.

2-Discuss the history of classification.

3-Discuss advantages and disadvantages of Bentham & Hooker’s classification.

4-Discuss International code of Nomenclature.

5-What do you understand by type? Describe various kinds of type.

6-What is effective and valid publication?

7-Write a note on:

a. Rules and recommendation
b. Principles
c. Valid and Effective publication
d. Binomial nomenclature

UNIT-05: INTRODUCTION TO ANGIOSPERM TAXONOMY

Contents:

5.1 OBJECTIVES

After reading this unit you will be able to understand:

- Different types of tissues
- Structure of root, stem and leaf
- Different types of ovules
- Embryo sac
- Endosperm
- Pollination
- Fertilization

5.2 INTRODUCTION

Students as you know that Plant anatomy or Phytotomy is the general term for the study of the internal structure of plants. The science of the structure of the organized plant body learned by dissection is called Plant Anatomy (anatomy-dissection). In general, plant anatomy refers to study of internal morphology, pertaining to different tissues. The subject of this chapter is internal structure of Angiosperms, with emphasis on primary tissues. While originally it included plant morphology, which is the description of the physical form and external structure of plants, since the mid-20th century the investigations of plant anatomy are considered a separate, distinct field, and plant anatomy refers to *just* the internal plant structures.

Ovules as you have read, are enclosed by the ovary wall. The part of the carpellary tissue to which the ovules are attached is called **placenta** and the distribution of ovules in the ovary is described as **placentation.** Ovule also known as megasporangium is the place of formation of the megaspores and the female gametophyte. The latter, after fertilization produces the embryo and endosperm, while the entire megasporangium with its enclosed structure becomes the seed and the progenitor of the next generation.

The capacity to reproduce is one of the most important characteristics of life and is aimed to sustain the individual species. Reproduction methods are mainly of two types- asexual and sexual. In flowering plants sexual method of reproduction requires fusion of two gametes, one from male organ and other from female organ of the plant. The product of the fusion of two different gametes is zygote and this fusion process is known as fertilization.

5.3 TYPES OF TISSUES

Now we will discuss the different types of tissue, but before this what are the tissues? In broad sense, a tissue may be defined as, "*a group of similar or dissimilar cells that perform a* *common function and have a common origin*." Plant body comprises different functions and for this it has different tissue system. For example epidermal tissue system protects inner cells and help in gaseous exchange; ground tissue system performs photosynthesis and the vascular tissue system helps in conduction of water and food. The various types of tissues are classified into three groups - **meristematic, permanent and secretary tissues.**

5.3.1 Meristem or Meristematic Tissue

Initially all embryonic cells of an embryo have the capacity to divide and multiply but as the embryo develops into a plant body, this capacity for division is restricted to certain parts of the plant body called meristems which are active throughout the life of the plant body (unlike that of an animal body). When meristematic cells divide, a group of the daughter cells remain meristematic; the other daughter cells called derivatives differentiate into various tissue elements. Before the occurrence of any cell division, usually cells become enlarged accompanied with addition of protoplasmic and cell wall material. So a meristmatic tissue is a group of cells that are in continuous state of division or retain their power of division (Fig.5.1). Meristmatic cells have some characteristics like:

- Meristematic cells may be rounded, oval or isodiametric in shape.
- Compactly arranged i.e. no intercellular space and with dense cytoplasm
- Large nucleus, and small vacuoles or without vacuoles
- Cell wall is thin and donot store reserve food material
- Always in active state of division and divide in a plane

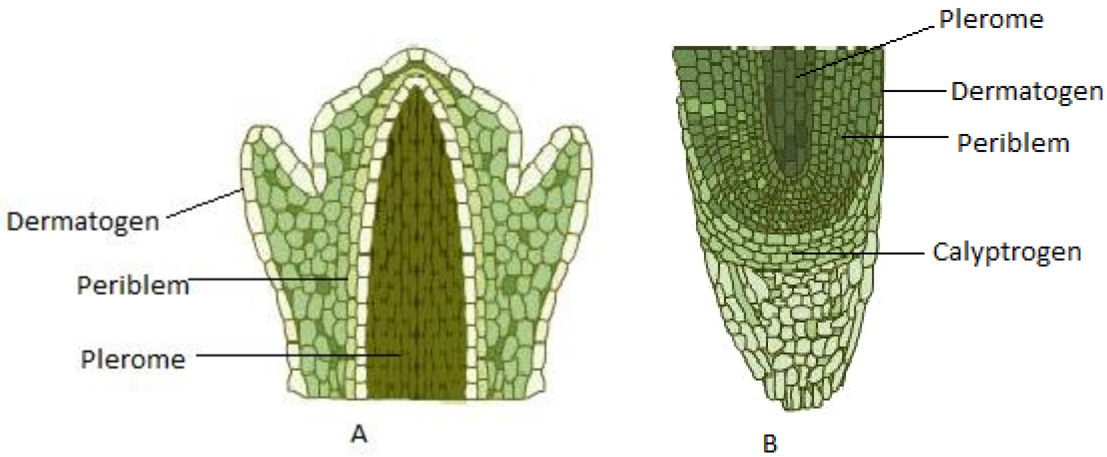


Fig.5.1: Meristematic tissue: A. Stem apex; B. Root apex

Meristems are located in the growing zones and after continuous division they regularly produce new cells, which later on after maturation forms the anatomical sections. This process is called differentiation in which the newly produced cells gets modify into the mature and permanent cells. Meristems which occur at the apices of stem, root and other branches are called apical meristems, which bring about primary growth of the plants, hence also called as primary meristems. On basis of origin it is classified as **primary meristem and secondary meristem.** Primary meristem develops at the stage of embryonic development and forms the primary plant body. The secondary meristem develops later on and forms the secondary tissue system of the plant body.

Types of Meristem: You are now well aware of meristems which are mainly responsible for the growth of the plants. Meristems are classified differently by workers like on basis of origin, position in plant body, plane of division and their function.

On basis of origin meristems are classified as:

- **Promeristem:** Group of cells which represent primary stage of meristematic cells. They are present in small region at the apices of shoots and roots. They give rise to primary meristem.
- **Primary Meristem:** The meristematic cells that originate from promeristem and these cells are always in active state of division and give rise to permanent tissue. In most monocots and herbaceous dicots only primary meristem is present.
- **Secondary Meristem:** They are the meristems developed from primary permanent tissue. They are not present from the very beginning of the organ but develop at a later stage and give rise to secondary permanent tissue. Secondary growth occurs due to these cells and plant increases in its diameter.

On the basis of position in plant body the meristem is of following type:

- **Apical Meristem:** It lies at the apices of root, stem and often in leaves as well. These are responsible for the growth of plants. These cells always maintain their position and capacity to divide. In higher vascular plants apical cells are found in groups but in vascular cryptogams it is found singly.
- **Intercalary Meristem:** This is also a primary meristem, found inserted between permanent tissues, in the bases of internodes and leaf sheaths of grasses. They originate from the apical meristem when their portions get portions get detached due to growth of the organ. Wherever stem is jointed, elongation of internodes is due to intercalary meristem as in Bamboos. Even prolonged growth of leaves, flowers and fruits may be regarded as an intercalary growth.
- **Lateral Meristem:** Found in the lateral zones of the plants and increase the diameter of the organ means they are responsible for growth in thickness. The vascular cambium and cork cambium are referred to as secondary meristems because they produce secondary tissues, and increase the thickness of the plant body. This process is called secondary growth, seen in Dicotyledons and Gymnosperms.

On the basis of plane of division in plant body the meristem is of following type:

- **Mass Meristem:** In this cell division occurs in all planes so that irregular shaped structure is formed e.g. endosperm.
- **Plate Meristem:** It consists of parallel layers of cell which divide anticlinally in two planes so that a plate like structure is seen. This pattern is seen in development of leaf lamina.
- **Rib or File Meristem:** In this type of development cells divide at right angles or anticlinally in one plane. It is found in the development of lateral roots.

Meristems are also classified on the basis of their function. These are classified as **protoderm-** the outermost tissue develops into epidermis, **procambium-** develops into primary vascular tissue and **ground meristem -** develops into ground tissue like cortex, pericycle and pith.

5.3.2 Permanent or Mature Tissues

Cells derived from meristems gradually change in their structure, metabolism and chemistry and acquire specialized characters by their various modes of differentiation. Not all the cells totally differ from the meristems. Some cells retain the power of division and others cannot divide. In a strict sense only those cells which have lost the power for division must be regarded as permanent tissues, but in a broad sense, cells derived from meristem that have acquired a special function like photosynthesis, secretion, storage are treated as part of matured tissue. The cells of these tissues may be living or dead and thin or thick walled. The thin walled tissue are generally living whereas the thick walled may be dead or living.

There are two types of mature or permanent tissues: Simple and Complex.

1: Simple Tissue: These tissues or group of cells are similar and simple type having different structural entities and mainly forms the vegetative plant body. Simple tissues are made up of one type of cells forming a uniform system of cell. On basis of structural difference these are of following three types:

a) Parenchyma (Para-beside, enchyma-In poured)

Parenchyma is the fundamental tissue of the plant body. It is found in every part of the plant body like pith and cortex of stem and root, mesophyll of leaves, flesh of fruits, floral parts and even in xylem and Phloem. Cells have thin primary walls and polyhedral shapes. Cells are compactly arranged or more commonly spaciously arranged with intercellular spaces as in cortex and pith. Cells possess dense cytoplasm and are active metabolites.

Parenchymatous cells may also perform specialized functions and are structurally modified. The turgid parenchyma helps in giving rigidity to the plat body. Partial conduction of water is also maintained through these cells. The following are the different types of parenchyma.

(i) Aerenchyma

(ii) Chlorenchyma

b) Collenchyma (Kolla - Glue)

Collenchyma is a simple, living tissue composed of elongated cells. Morphologically it is a simple tissue because of having one type of cells. Cell walls are thickened due to deposition of pectin. Collenchyma is the primary supporting tissue in stems, leaves and floral parts of dicots, where as in stems and leaves of monocots collenchyma is usually absent, (instead, sclerenchyma is present in monocots). The most important character of this tissue is its early development and its adaptability to change in rapid growing organ.

Collenchyma is usually hypodermal in position just beneath the epidermis and typical supporting organ. Cells are more elongated and narrower than parenchyma. Like parenchyma, collenchyma may also contain chloroplasts or may regain the thickening. Intercellular spaces may or may not be present.

c) Sclerenchyma (Scleros-hard)

Cells of sclerenchyma are thick walled and are usually lignified. The thickness is due to formation of secondary wall. At least initial the secondary wall is free from primary wall. At maturity, usually the cells are devoid of protoplast means they are dead one. The cell wall encloses a cavity lumen and on the cell wall, pits are usually present (simple type). This is supporting tissue that withstands various strains resulting from stretching and bending of plant organ without any damage. They are of various shape and size; even some of these cells are longest in plant kingdom. The primary function of this tissue is to provide mechanical support. Commonly sclerenchyma cells are classified into fibers and sclereids.

Fibers: These are usually long, spindle shaped structures, with tapering or blunt ends. Longest fiber is seen in *Boehmeria nivea* (55 cms). They are arranged in groups. Secondary thickening may account for 90% of the area of the cell; the lumen is narrow. Cells have pits which are very small, round or slit like and often oblique. Fibers are grouped into xylary fibers and extraxylary fibers. Xylary fibers, also called wood fibers are parts of xylem and are longest among xylem elements.

The fiber cells are classified according to their mode of origin. They can be classified into three groups: 1- Surface fibers, 2- Wood fibers and 3-Bast fibers.

Sclereids: These are shorter than fibers with thick wall and spherical, oval and cylindrical shape. Sclereids occur singly or in groups with lignified walls and cells devoid of living content. Sclereids are commonly found in fruit wall, seed coat, epidermal scales, and occasionally found in cortex, pith, mesophyll and petiole of submerged aquatics. They can be obtained from the endocarp of the almond and coconut and from the hard seed coats of some leguminous seeds (*Pisum*, *Phaseolus*).

2. **Complex Tissue:** A complex tissue means *collection of different types of cell that perform a common function.* Xylem and the phloem are examples of complex tissues because these transportation organs are made up of more than one type of cells. Both of these structures are assemblage of living and nonliving cells, they constitute different shaped and sized cells. Xylem and phloem tissues are collectively known as vascular tissue.

Vascular Tissue

This tissue is a complex tissue and is heterogeneous in nature with different types of cells. Its role is conduction of food, water and minerals in the plant body and the chief elements are xylem and phloem.

(i) Xylem (Wood): Vascular plants have evolved a highly specialized tissue called xylem, which provides mechanical support and transports water, mineral nutrients and phytohormonal signals in the plant. Although it is the most abundant biological tissue on earth, much remains to be learned about the structure, function, development and evolution of xylem and of the genes that regulate the processes. Xylem is the water conducting tissue from roots to leaves. It consists of living cells like parenchyma and dead cells like tracheary elements, along with these fibers are also present.

(ii)Phloem (Bast)

Phloem is the complex food conducting tissue and also known as bast. It is composed of sieve elements, companion cells, parenchyma cells and fibers. Like xylem all these types of cells are not of universal occurrence. In Gymnosperms and the Pteridophytes the companion cells are absent. In some hydrophytes there is no evident differentiation of these cells. Phloem differentiated from procambium is called primary phloem; secondary phloem is initiated from vascular cambium.

Primary phloem: This is classified into protophloem and metaphloem. In protophloem, sieve tube members are without companion cells. Sieve tubes function for a brief period and soon they get crushed by the surrounding pressure. The crushed cells may disappear. Metaphloem tissue survives for a longer period. Its elements are longer and wider. Usually fibers are absent in dicotyledons, whereas in monocotyledons and herbaceous dicots, parenchyma cells are present.

Secondary phloem: Similar to secondary xylem, there are two systems of arrangements in secondary phloem:

1) Axial system producing sieve elements, phloem parenchyma and phloem fibers.
2) Transverse system producing ray parenchyma cells.

Pericycle (A Circle All Around)

Pericycle is the region, consisting of one - few layers of cells, found external to central cylinder (stele) e.g. roots and dicot stems. Pericycle may be composed of parenchyma cells or sclerenchyma cells or both. Lateral branches and phellogen may arise from pericycle.

5.3.3 Specialized tissue or Secretary Tissue

Cell or organizations of cells which produce a variety of secretions are called secretory tissues. The secreted substance may remain deposited within the secretory cell itself or may be excreted, that is, released from the cell. Substances may be excreted to the surface of the plant or into intercellular cavities or canals. Some of the many substances contained in the secretions are not further utilized by the plant (resins, rubber, tannins, and various crystals), while others take part in the functions of the plant (enzymes and hormones). Secretory structures range from single cells scattered among other kinds of cells to complex structures involving many cells; the latter are often called glands.

Epidermal hairs of many plants are secretory or glandular. Such hairs commonly have a head composed of one or more secretory cells borne on a stalk. The hair of a stinging needle is bulbous below and extends into a long, fine process above. If one touches the hair, its tip breaks off, the sharp edge penetrates the skin, and the poisonous secretion is released. Glands secreting a sugary liquid-the nectar-in flowers pollinated by insects is called nectaries. Nectaries may occur on the floral stalk or on any floral organ like sepal, petal, stamen, or ovary.

The hydathode structures discharge water- a phenomenon called guttation through openings in margins or tips of leaves. The water flows through the xylem to its endings in the leaf and then through the intercellular spaces of the hydathode tissue toward the openings in the epidermis. Strictly speaking, such hydathodes are not glands because they are passive with regard to the flow of water.

As a result of cellular processes, substances that are left to accumulate within the cell can sometimes damage the protoplasm. Thus it is essential that these materials are either isolated from the protoplasm in which they originate, or be moved outside the plant body. Although most of these substances are waste products, some substances are vital to normal plant functions. Examples: oils in citrus, pine resin, latex, opium, nectar, perfumes and plant hormones. Generally, secretory cells are derived from parenchyma cells and may function on their own or as a tissue. They sometimes have great commercial value. There are a large number of plants in the world which have special cells or groups of cells that secrete or excrete products from the plant body. The tissues that are concerned with the secretion of gums, resins, volatile oils, nectar latex, and other substances in plants are called **secretory tissues.** These tissues are divided into two groups.

1. Laticiferous tissues

These consist of thin walled, greatly elongated and much branched ducts containing a milky or yellowish colored juice known as latex. This mixture storage, generally milky white, other colors rarely, form an emulsion which are active ingredients as protein, carbohydrates, enzymes, tannins, rubber, hormones and alkaloids and is called latex. A plant rich in latex is the papaya. They irregularly distributed in the mass of parenchymatous cells. Laticiferous ducts, in which latex are found are again two types:

Latex cell or non-articulate latex ducts

Latex vessels or articulate latex

2. Glandular tissues

This tissue consists of special structures called the glands. These glands contain some secretory or excretory products. A gland may consist of isolated cells or small group cells with or without a central cavity. They are of various kinds and may be internal or external.

Internal glands are:

- Oil-gland secreting essential oils, as in the fruits and leaves of orange, lemon.
- Mucilage secreting glands as in the betel leaf.
- Glands secreting gum, resin, tannin etc.
- Digestive glands secreting enzymes or digestive agents.
- Special water secreting glands at the tip of veins.

External glands are commonly short hairs tipped by glands. They are:

- water-secreting hairs or glands.

- Glandular hairs secreting gum like substances as in tobacco, plumbago etc.
- Glandular hairs secreting irritating, poisonous substances as in nettles.
- Honey glands as in carnivorous plants.

Gum ducts are similar to resin ducts and may contain resins, oils, and gums. Usually, the term gum duct is used with reference to the dicotyledons, although gum ducts also may occur in the gymnosperms. Oil ducts are intercellular canals whose secretory cells produce oils or similar substances. Such ducts may be seen, for example, in various parts of the plant of the carrot family (Apiaceae). Laticifers are cells or systems of cells containing latex, a milky or clear, colored or colorless liquid. Latex occurs under pressure and exudes from the plant when the latter is cut.

Lysigenous cavities are formed by cavities coming from cell groups which are loaded of secretory products and whose protoplasm membranes have been destroyed gradually. This group of cells is also called "pockets" of secretion and can be found in fruits and young stems of citrus.

Schizogenous cavities are the cells or epithelial located inside the parenchyma tissue or inside other tissues. They always wrap rounded or irregular intercellular spaces, or intercellular ducts, simple or branched, which sometimes go through all the plant as communications ducts. These intercellular spaces are caused by separation of the glandular cells and are the containers of the developed products; they are the schizogenous cavities or secretion cavities (Fig. 5.2). According to its contents, these are distinguished ducts or cavities with lipids (essential oils), resins, gums and mucilage.

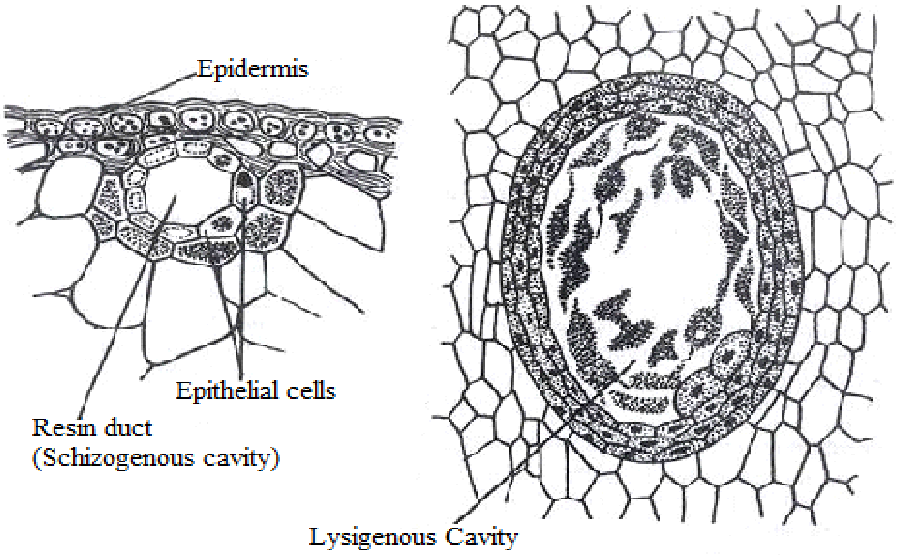


Fig. 5.2: Structure of Schizogenous and Lysigenous cavities

5.4 STRUCTURE OF ROOT

Evolutionarily, the root seemed to be the last of the three main vegetative organs to evolve, perhaps since early land plants grew on or near the water and so much of their early innovations were geared toward maximizing photosynthesis through development of stems and leaves. There are generally two very different developmental and structural aspects to Angiosperm root systems. The primary root system is derived from the radicle and tends to be dominant in dicots, and gives rise to lateral roots with various degrees of branching. In monocots, the primary root is often ephemeral, and so adventitious roots (derived usually from stems and leaves) and seminal roots (derived from mesocotyl) comprise their root systems where they also produce lateral roots.

The root system also has an apical meristem, known as the **root apical meristem**. This acts in much the same way as the shoot apical meristem, causing extension growth. The main difference is the growth goes down into the ground, and roots, not leaves and branches come from the root apical meristem. Roots have really important jobs, and they do not get due credit for their hard work because they remain underground all the time. Roots are responsible for:

- Anchoring the plant into the ground
- Absorbing water and nutrients
- Storing nutrients
- Associating with soil microbes in symbiotic relationships

As roots grow, they travel downward through the soil, dodging rocks and other obstacles that might be in their way. Just as you should wear a helmet when riding a motorcycle or playing hockey, roots have their own type of helmet: a **root cap**. The root cap protects the root apical meristem as the root pushes its way through the soil. It also secretes slimy ooze that lubricates the soil around the tip of the root, aiding the root on its journey through the harsh soil.

Anatomy of root is simpler than stem and show some characteristic features by which we can determine roots. They lack chlorophyll and are positively geotropic and they are not susceptible to light. Roots have root cap at the apex with root hairs near the apex. Vascular bundles are radial and exarch type i.e. xylem and phloem in different radii and protoxylem towards periphery and metaxylem towards center.

Anatomical Characters:

We can understand root anatomy as per the Angiospermic plant group i.e. monocot and dicot plants. Both of these plant groups has different anatomical features and given in detail here.

Anatomy of Dicot Root: The important anatomical features of a dicot root are visible in the cross section of a dicot plant and following tissues are seen (Fig. 5.3):

Epiblema (Epidermis): Epiblema is made up of thin walled living cells (parenchymatous) that are compactly arranged. This is the outermost layer in root and some of these cells form root hairs. Root hairs are outgrowth of epidermal cell and help in both absorption and anchorage. Root hairs are unicellular, long and tubular. Root epidermis is devoid of stomata although stomata are found in some species. The breathing roots in the halophytes possess specialised pores in the epidermis. These are called lenticels and such roots are called pneumatophores. The main function of the epidermis is protection and absorption of water and solutes.

Cortex: Root cortex composed of thin walled cells with lots of intercellular spaces. Cells are usually oval, rounded and polygonal in shape with a distinct mode of arrangement. In some herbaceous dicots which lack secondary growth, the cortex permanently retained and develops various types of mechanical tissues. Even chloroplast is reported in the cortex of

Tinospora sp. Tannin cells, mucilage cells and latex cells are also found in the cortical region of dicot roots. In most of the dicots the cortex is replaced by suberized cells as a result of secondary growth. Cortical cells help in gaseous exchange, passage of absorbed water, maintain root pressure and during secondary growth regain meristmatic activity and gives rise to cork cambium.

Endodermis: This is a uniseriate layer forming the central cylinder of the plant. Endodermis is a distinct layer having living cell with casparian strips in their radial and transverse wall. Casparian strips are actually bands of suberin deposited on the walls of endodermis. The endodermis is generally destroyed after secondary growth. The casparian strip maintains the movement of materials in the root and their passage into xylem cells. Endodermis not only regulates the movement of materials in the root and their passage into the xylem but also contains the starch grain, performing storage function as well.

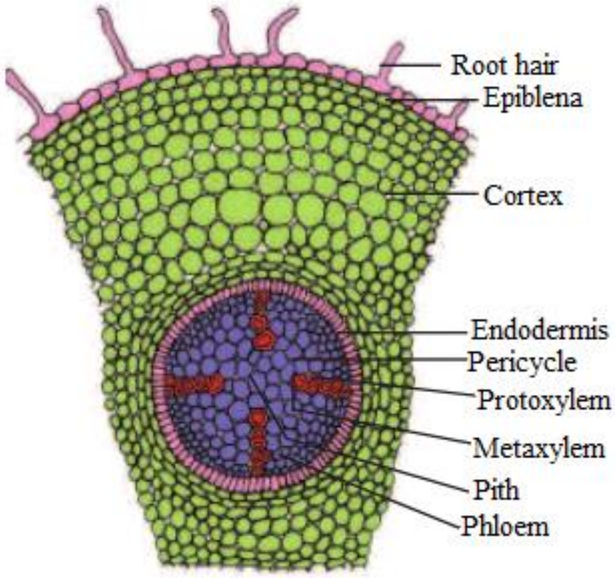


Fig. 5.3: T.S. of Dicot root

Pericycle: This is a thin walled parenchymatous cell layer next to epidermis. It may be uni or multiseriate and responsible to give rise the lateral roots. It maintains its meristmatic activity so that it produces lateral roots, phellogen and some part of vascular cambium.

Vascular bundles: Vascular bundles are radial and tetrarch. There are four bundles each of xylem and phloem occurring alternately. Xylem is described as exarch i.e. metaxylem towards centre and protoxylem towards periphery.

Pith: Pith is absent in the older root.

Anatomy of Monocot Root: The important anatomical features of a monocot roots are visible in the cross section of a monocot plant and following tissues are seen (Fig. 5.4):

Epiblema (Epidermis) : Epiblema is the outermost covering of the root formed by a single layer of compactly arranged, barrel-shaped parenchyma cells. The cells are characteristically thin-walled since they are involved in absorption of water. A cuticle and stomata are absent. Some of the epiblema cells are produced into long unicellular projections called root hairs. Hence, epiblema is also known as piliferous layer.

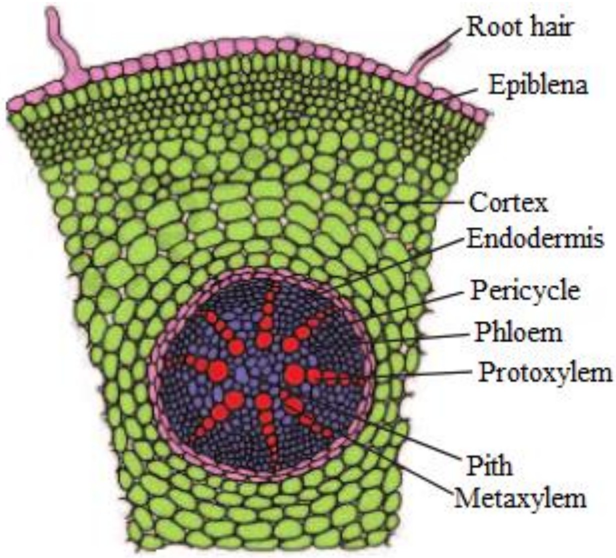


Fig. 5.4: T.S. of Monocot root

Cortex: Cortex is a major component of the ground tissue of root. It is represented by several layers of loosely arranged parenchyma cells. Intercellular spaces are prominent. The cortex is mainly meant for storage of water. The cells also allow a free movement of water into the xylem vessels.

Endodermis: It is the innermost layer of cortex formed by compactly arranged barrel-shaped cells. Some of the cells in the endodermis are thin-walled and are known as passage cells. The passage cells allow water to pass into the xylem vessels. The remaining cells in the endodermis are characterised by the presence of thickening on their radial walls. These thickenings are known as casparian thickenings. They are formed by the deposition of a waxy substance called suberin. The casparian thickenings play an important role in creating and maintaining a physical force called root pressure.

Stele: Stele is the central cylinder of the root consisting of pericycle, conjunctive tissue, pith and vascular bundles.

Pericycle: Pericycle is the outermost covering of the stele represented by a single layer of parenchyma cells.

Conjunctive tissue: It is represented by loosely arranged parenchyma cells found in between the vascular bundles. The cells are specialized for storage of water.

Pith: Pith is the innermost region of the root representing the central axis. It is composed of few loosely arranged parenchyma cells.

Vascular bundles: Vascular bundles are radial in arrangement. There are eight bundles each of xylem and phloem. Hence, the condition is described as polyarch. Xylem is described as exarch.

Dicot root

1. Cortex is comparatively narrow
2. Pericycle is single layered
3. Pericycle produces lateral roots cambium and cork cambium

4. Vascular bundles range from two to six in number
5. Xylem vessels are angular
6. Pith is not well developed or absent
7. Secondary growth takes place

Monocot root

1. Cortex is wide
2. Pericycle is often multilayered
3. Pericycle produces lateral roots
4. Vascular bundles are more than six in number
5. Xylem vessels are oval or rounded
6. Pith is well developed
7. Secondary growth does not take place

S. No.	Monocot Root	Dicot Root
1	A large number of vascular bundles	A limited number of vascular bundles.
2	The vascular bundles are scattered in the ground tissue	The vascular bundles are arranged in a ring
3	No cambium occurs between the xylem and phloem	Cambium occurs between the xylem and phloem
4	There is no distinction between the cortex and pith	The cortex and pith can be clearly distinguished
5	No Secondary thickening	Secondary thickening can occur
6	No annual rings are formed	Annual rings are formed due to secondary thickening

5.5 STRUCTURE OF STEM

Stems are usually above ground organs and grow towards light (positively phototropic) and away from the ground (negatively geotropic), except in the case of certain metamorphic (modified) stems. The main stem develops from the plumule of the embryo, while lateral branches develop from auxillary buds or from adventitious buds. In normal stems clearly defined internodes and nodes can be distinguished, the latter being the regions where the leaves are attached. In younger stems stomata are found in the epidermis while in the mature stems lenticels are evident. Depending on the hardness of the stem one can also distinguish between herbaceous and woody stems. In this section we will discuss the internal structures of young dicotyledonous and monocotyledonous stems, secondary thickening in the stems of dicot, and differences in the internal structures of dicots and monocots.

Stem is one of two main structural axes of a vascular plant, the other being the root. The stem is normally divided into nodes and internodes: The nodes hold one or more leaves, as well as buds which can grow into branches {with leaves, conifer cones or inflorescences (flowers)}. Adventitious roots may also be produced from the nodes.

The term "shoots" is often confused with "stems"; "shoots" generally refers to new fresh plant growth including both stems and other structures like leaves or flowers. In most plants stems are located above the soil surface but some plants have underground stems.

Stems have four main functions which are:

- Support for and the elevation of leaves, flowers and fruits
- The stems keep the leaves in the light and provide a place for the plant to keep its flowers and fruits
- Transport of fluid between the root and shoot by the xylem and phloem
- Storage of nutrients

Production of new living tissue i.e. stems have cells called meristems that annually generate new living tissue. **Shoots** consist of stems including their appendages, the leaves and lateral buds, flowering stems and flower buds. The new growth from seed germination that grows upward is a **shoot** where leaves will develop. In the spring, perennial plant shoots are the new growth that grows from the ground in herbaceous plants or the new stem and/or flower growth that grows on woody plants.

In everyday speech, shoots are often synonymous with stems. Stems, which are an integral component of shoots, provide an axis for buds, fruits, and leaves. Young shoots are often eaten by animals because the fibers in the new growth have not yet completed secondary cell wall development, making the young shoots softer and easier to chew and digest. As shoots grow and age, the cells develop secondary cell walls that have a hard and tough structure. Some plants (e.g. bracken) produce toxins that make their shoots inedible or less palatable

Stem usually consist of three tissues, dermal tissue, ground tissue and vascular tissue. The dermal tissue covers the outer surface of the stem and usually functions to water proof, protect and control gas exchange. The ground tissue usually consists mainly of parenchyma cells and fills in around the vascular tissue. It sometimes functions in photosynthesis. Vascular tissue provides long distance transport and structural support. Most or all ground tissue may be lost in woody stems. The dermal tissue in aquatic plants, stems may lack the waterproofing as found in aerial stems. The arrangement of the vascular tissues varies widely among plant species.

Dicot stems

Dicot stems with primary growth have pith in the center, with vascular bundles forming a distinct ring visible when the stem is viewed in cross section. The outside of the stem is covered with an epidermis, which is covered by a waterproof cuticle. The epidermis also may contain stomata for gas exchange and multicellular stem hairs called trichomes. A cortex consisting of hypodermis (collenchyma cells) and endodermis (starch containing cells) is present above the pericycle and vascular bundles.

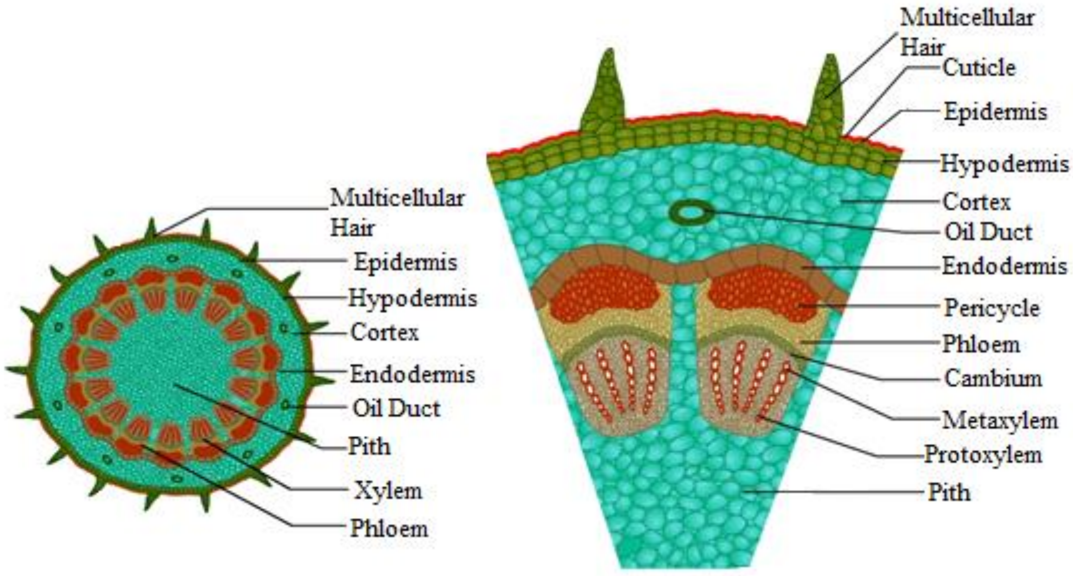


Fig.5.5: T. S. of Dicot stem; A. Diagrammatic; B. A portion enlarged

From the study of the transverse section of the dicotyledonous stem you will identify the following three regions of tissues: epidermis, cortex and vascular cylinder or stele (Fig. 5.5).

Epidermis: The epidermis consists of a single layer of living cells which are closely packed. The walls are thickened and covered with a thin waterproof layer called the cuticle. Stomata with guard cells are found in the epidermis. In some stems either unicellular or multicellular hair-like outgrowths, trichomes, appear from the epidermis.

- The epidermis *protects the underlying tissues*
- The cuticle *prevents the desiccation of inner tissues* and thus *prevents water loss*
- The stomata allow *gaseous exchange* for the processes of respiration and photosynthesis

Cortex: This region comprises the cells of collenchyma, parenchyma and endodermis. It is situated to the inside of the epidermis. Collenchyma cells lie under the epidermis and constitute three to four layers of cells with cell walls thickened at the corners. The collenchyma cells contain chloroplasts. This tissue serves to *strengthen* the young stem. The chloroplasts are responsible for the *synthesis of organic food* during photosynthesis. Beneath the collenchyma cells are a few layers of thin-walled cells, parenchyma, with intercellular spaces. The parenchyma cells make up the bulk of the cortex. They synthesized *organic food (mainly starch)* is *stored here*. The intercellular air spaces are responsible for *gaseous exchange*.

Endodermis: It is starch sheath which forms the innermost layer of the cortex. This is a single layer of tightly-packed rectangular cells bordering the stele of the stem. The cells of this tissue *store starch*. It allows *solutions to pass from the vascular bundles to the cortex*.

Vascular cylinder or Stele: This region comprises the pericycle, vascular bundles and pith (medulla). The pericycle is made up of sclerenchyma cells which are lignified, dead fiber cells. These cells have thick, woody walls and tapering ends. It *strengthens* the stem. This distinct ring of vascular bundles is a distinguishing characteristic of dicotyledonous stems. A mature vascular bundle consists of three main tissues - xylem, phloem and cambium. The phloem is located towards the outside of the bundle and the xylem towards the center. The cambium separates the xylem and phloem which bring about secondary thickening.

The xylem provides a *passage for water and dissolved ions* from the root system to the leaves. The xylem also *strengthens and supports* the stem. The phloem *transports synthesized organic food* from the leaves to other parts of the plant. The cambium, divides to produce new xylem and phloem cells, making *secondary thickening* possible.

Monocot stems

Vascular bundles are present throughout the monocot stem, although concentrated towards the outside. This differs from the dicot stem that has a ring of vascular bundles and often none in the center. The shoot apex in monocot stems is more elongated. Leaf sheathes grow up around it to protect it. This is true to some extent of almost all monocots. Monocots rarely produce secondary growth and are therefore seldom woody, with Palms and Bamboos being notable exceptions. However, many monocot stems increase in diameter due to anomalous secondary growth (Fig. 5.6).

The tissues of dicots and monocots are basically the same as you will see. However, there are essential differences in the arrangement of the epidermis, ground tissue and vascular tissue (Fig. 5.7).

The structure and functions of **Epidermis** is same as the epidermis of the stem of a dicotyledonous plant. The epidermis consists of a single layer of living cells which are closely packed. The walls are thickened and covered with a thin waterproof layer called the cuticle. Stomata with guard cells are found in the epidermis. In some stems either unicellular or multicellular hair-like outgrowths, trichomes, appear from the epidermis. The epidermis *protects the underlying tissues*. The cuticle *prevents the desiccation of inner tissues* and thus *prevents water loss.* The stoma allows *gaseous exchange* for the processes of respiration and photosynthesis.

Ground Tissue composed of small, thick-walled sclerenchyma on the inside of the epidermis. These layers of cells are followed by larger thin-walled parenchyma cells. Intercellular air spaces are found in the parenchyma. Cortex and pith are absent. Sclerenchyma tissue *strengthens* the stem. Parenchyma tissue *stores synthesized organic food* such as starch. Intercellular air spaces allow the *exchange of gases*.

The vascular bundles are found scattered throughout the ground tissue. The vascular bundles occurring nearer the rind of the stem are smaller and are closer to one another. The vascular bundles contain no cambium and consequently secondary thickening does not occur. Thick-walled sclerenchyma fibers surround the vascular bundle. Sclerenchyma sheaths *protect the vascular* bundles and give *strength* to the stem. Large xylem vessels are found within an irregular intercellular air space called the lysigenous cavity. This space is surrounded by thin-walled parenchyma cells. Phloem is composed of thin-walled cells, viz. sieve tubes and companion cells.

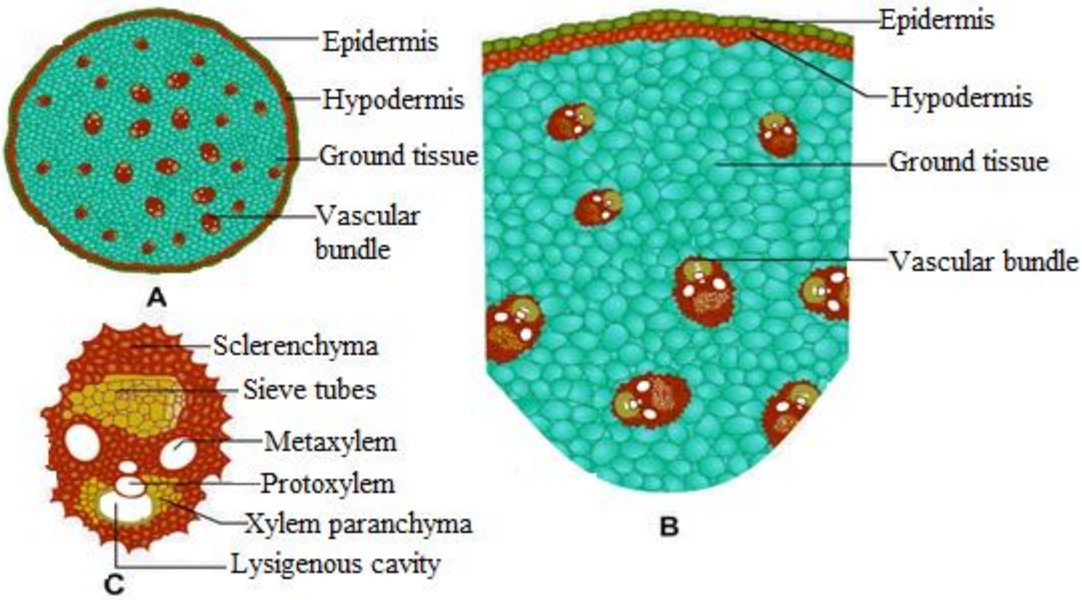


Fig.5.6: T.S. of Monocot stem; A. Diagrammatic; B. A portion enlarged; C.Single vascular bundle

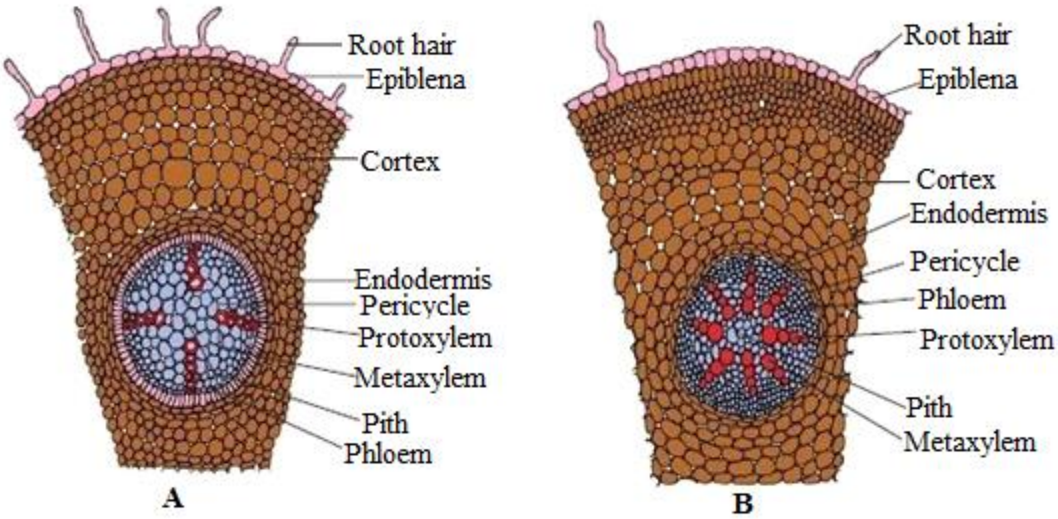


Fig.5.7: T.S. of root; A. Dicot root; B. Monocot root

Comparison of dicot and monocot stem anatomy

S. No.	Dicot Stem	Monocot Stem
1	Single layered epidermis with thick cuticle	Single layered epidermis with thick cuticle.
2	Multicellular epidermal hairs may or may not be present	Epidermal hairs absent
3	Hypodermis is generally collenchymatous	Hypodermis is generally sclerenchymatous
4	The different tissues are arranged in concentric fashion	Concentric arrangement is absent

5	Ground tissue is differentiated into hypodermis, cortex, endodermis, pericycle and pith	No differentiation except hypodermis
6	Always solid	Solid or hollow
7	Vascular bundles are of similar size	Vascular bundles are of different sizes
8	Vascular bundles are wedge shaped, definite and arranged in one or two rings	Oval or rounded, numerous and scattered in the ground tissue
9	Bundle sheath absent	Bundle sheath present
10	Vascular bundles conjoint, collateral or bicollateral and open	Conjoint, collateral and closed
11	No cavity in the vascular bundles	A protoxylem cavity present
12	Vessels are polygonal, numerous and arranged in chains	Vessels are oval, few and arranged like the letter V or Y
13	Phloem parenchyma present	Phloem parenchyma absent
14	Secondary growth occurs due to formation of lateral meristem	Secondary growth is generally absent

5.6 STRUCTURE OF LEAF

A **leaf** is an organ of a vascular plant and is the principal lateral appendage of the stem. The leaves and stem together form the shoot. **Foliage** is a mass noun that refers to leaves collectively. Typically a leaf is a thin, dorsiventrally flattened organ, borne above ground and specialized for photosynthesis. Most leaves have distinctive upper (adaxial) and lower (abaxial) surfaces that differ in colour, hairiness, the number of stomata (pores that intake and output gases) and other features. In most plant species, leaves are broad and flat. Such species are referred to as broad-leaved plants. Many Gymnosperm species have thin needle-like leaves that can be advantageous in cold climates frequented by snow and frost. Leaves can also have other shapes and forms such as the scales in certain species of conifers. Some leaves are not above ground (such as bulb scales). Succulent plants often have thick juicy leaves, but some leaves are without major photosynthetic function and may be dead at maturity, as in some cataphylls, and spines). The primary site of photosynthesis in most leaves (palisade mesophyll) almost always occurs on the upper side of the blade or lamina of the leaf but in some species, including the mature foliage of *Eucalyptus* palisade occurs on both sides and the leaves are said to be isobilateral.
The leaf is the primary photosynthetic organ of the plant. It consists of a flattened portion, called the blade, which is attached to the plant by a structure called the petiole. Sometimes leaves are divided into two or more sections called leaflets. Leaves with a single undivided blade are called simple leaf, those with two or more leaflets are called compound leaf.

The structure of leaf shows following cell composition.

Epidermis: A leaf is made of many layers that are sandwiched between two layers of tough skin cells (called the epidermis). The epidermis also secretes a waxy substance called the cuticle. These layers protect the leaf from insects, bacteria, and other pests. Among the epidermal cells are pairs of sausage-shaped guard cells. Each pair of guard cells forms a pore (called stoma; the plural is stomata). Gases enter and exit the leaf through the stomata. The epidermal cells are barrel-shaped, compactly arranged; upper epidermis is covered with thick cuticle and lacks stomata; lower epidermis is light green, covered with thin cuticle and is interrupted by stomata. Epidermis helps the plant by:

- The cuticle *prevents water loss*
- The epidermis *protects the internal tissues* from injury
- The stomata *allows for gaseous exchange for photosynthesis and respiration*

Vascular tissue: The vascular tissue, xylem and phloem are found within the veins of the leaf. Veins are actually extensions that run from to tips of the roots all the way up to the edges of the leaves. The outer layer of the vein is made of cells called **bundle sheath cells** (E), and they create a circle around the xylem and the phloem. On the picture, **xylem** is the upper layer of cells (G) and is shaded a little lighter than the lower layer of cells - **phloem** (H). Recall that xylem transports water and phloem transports sugar (food).

Dicot and monocot plants have different leaf morphology and anatomy and their description is given below.

Monocot leaf: Example: Maize.

The leaf of monocot plants is known as isobilateral and is vertically oriented.

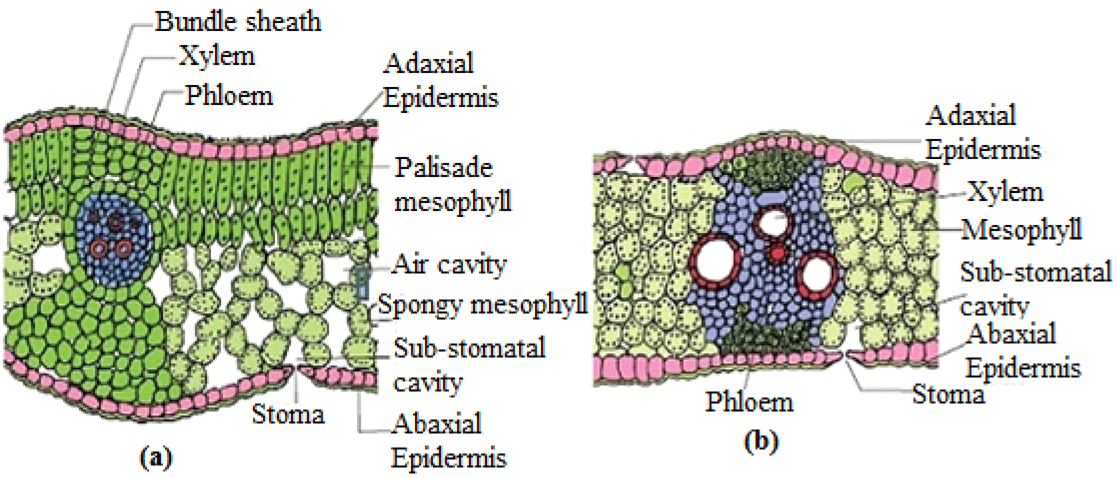


Fig.5.8: A.T.S. of Dicot leaf; B. T.S. of Monocot leaf

Dicot leaf: Example: Sunflower

It is more strongly illuminated on the upper surface than the lower. This unequal illumination induces a difference in the internal structure between upper and lower sides.

Comparison between the leaf structures of Dicot and Monocot:

Characters	Dicot Leaf e.g. Mango leaf	Monocot Leaf e.g. Maize leaf
1. Orientation of Leaf	Horizontal, dorsiventrally differentiated	Vertical, isobilateral
2. Stomata	Usually on lower epidermis	On both epidermal layers
3. Cuticle	Thick on upper epidermis	Thick on both epidermal layers

4. Motor cells	Absent	Present in upper epidermis
5. Mesophyll	Differentiated into upper palisade parenchyma and lower spongy parenchyma	No differentiation of mesophyll
6.Vascular bundles	All of them are not seen in parallel series and are supported by bundle sheath extension	Vascular bundles are in parallel series and are supported by sclerenchyma patches

5.7 TYPES OF OVULES

The **megasporangium or ovule** consists of **nucellus** and its protective coats, the **integuments**. It is attached to the placenta, on the inner wall of ovary by a stalk called **funiculus (funicle)** and the point of attachment of the body of the ovule to the funiculus is called **hilum.**

A mature ovule, ready for fertilization, consists of nucellus enveloped almost completely by one or two sheaths, known as **integuments**, leaving a small opening at the apical end. This opening is known as **micropyle**. The basal region of the ovule where it is attached to the placenta by funicle, is called **chalaza** and so this side is known as chalazal end. Its opposite end is termed as micropylar end, the main passage for the entry of the pollen tube into the ovule. In the nucellus, **female gametophyte** is present, also known as **embryo sac.**

On the basis of the position of the micropyle with respect to the funiculus, mature ovule can be classified into six main types. These are:

1. Orthotropous
2. Anatropous
3. Campylotropous
4. Amphitropous
5. Hemianatropous
6. Circinotropous

1. **Orthotropous ovule:** Orthotropous ovule is also known as **atropous**. It is upright. In this type the micropyle, chalaza and the funiculus lie in one straight line as in Polygonaceae and Piperaceae (Fig. 5.9).

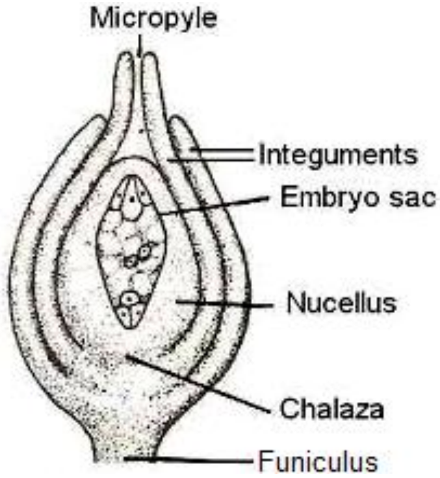


Fig. 5.9: Orthotropous ovule

2. Anatropous ovule: In this type, the funiculus is long; the body of the ovule becomes completely inverted so that micropyle comes to lie close to the base of the funiculus. This happens due to unilateral growth of the ovule. The nucellus remains straight so micropyle and chalaza lie in one line and funiculus lie parallel to it. It is the most common type of ovule in Angiosperms (Fig.5.10).

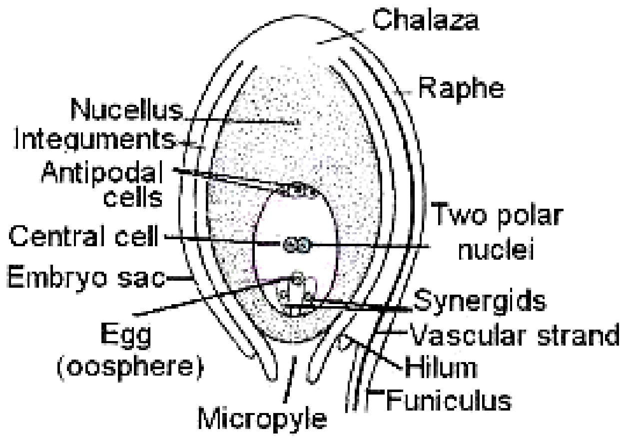


Fig. 5.10: Anatropous ovule

3. Campylotropous ovule: In campylotropous ovules body of the ovule is not completely inverted, the curvature is less than that in anatropous ovules. The micropyle and chalaza do not lie in the straight line and the funiculus lies at right angle to the chalaza as in Chenopodiaceae and Capparaceae (Fig. 5.11).

Fig. 5.11: Campylotropous ovule

4. Amphitropous ovule: It is similar to campylotropous, but in this case the curvature of the ovule also affects the nucellus/embryo-sac so that it bent like 'horse shoe' as in Alismaceae and Butomaceae (Fig. 5.12).

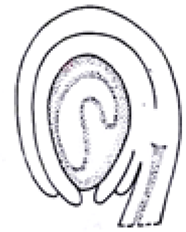


Fig. 5.12: Amphitropous ovule

5. Hemianatropous ovule: Also known as **hemitropous**. In this type of ovule the funiculus is at right angle to the nucellus and the integuments. Micropyle and chalaza, lie in the same plane as in *Ranunculus*, *Nothoscordum*, and *Tulbaghia* (Fig. 5.13).

Fig. 5.13: Hemianatropous ovule

6. Circinotropous ovule: A very peculiar type of ovule is seen in some members of the Plumbaginaceae. Here the nucellar protuberance is at first in the same line as the axis, but the rapid growth on one side causes it to become anatropous. The curvature does not stop but continues until the ovule has turned over completely so that the micropylar end again points upwards. It has been suggested that this kind of ovule, also seen in *Opuntia*, is distinctive enough to merit a separate name, Circinotropous (Archibald, 1939). (Fig. 5.14).

Fig. 5.14: Circinotropous ovule

5.8 EMBRYO SAC

The **female gametophyte** (embryo sac) is 7-celled (mostly), 8-nucleate structure having **three cells** of egg apparatus (two synergid cells and one egg cell) at the micropylar end, **three cells** (antipodal cells) at the chalazal end and **one cell** (centre cell) in the centre having two polar nuclei. This type of embryo sac is designated as the *Polygonum* type.

This mode of embryo sac development occurs in the majority of flowering plants. According to Davis (1966), about 81 per cent of the families show *Polygonum* type of embryo sac development. Two polar nuclei later fuse to form the secondary nucleus so you can also say that the central cell is binucleate or diploid and the antipodal cells and cells of the egg apparatus are uninucleate and haploid.

Types of embryo sac

The *Polygonum* type of embryo sac as described above is formed from one of the four haploid megaspore nuclei which in turn formed from diploid megaspore mother cell as a result of meiosis. Although it is the most common type of mode of embryo sac development in Angiosperms, even there is a substantial number of plants where more than one megaspore nuclei take part in the process.

Therefore **depending on the basis of involvement of number of megaspore nuclei** in its formation, the embryo sac can be of different types:

1. Monosporic
2. Bisporic
3. Tetrasporic

5.9 ENDOSPERM

The **oospore (zygote),** formed as a result of fusion of one male gamete with the egg, **develops into the embryo** while the **primary endosperm nucleus-** product of triple fusion, **develops the endosperm**. The other nuclei or cells within the embryo sac (synergids, antipodal cells) disorganize sooner or later.

Development of the Endosperm

The primary endosperm nucleus is a product of triple fusion. This undergoes a series of divisions and ultimately forms **endosperm.** The Angiospermic endosperm is a triploid (3n) tissue as it is a **product of triple fusion.** It is formed either by the fusion of one haploid male gamete and one diploid secondary nucleus (fusion product of two haploid polar nuclei) or by the fusion of three haploid nuclei (one male gamete belongs to male gametophyte and two polar nuclei belongs to the female gametophyte).

It is therefore **distinct from the endosperm of heterosporous Pteridophytes and Gymnosperms** where the endosperm is a simple haploid (n) tissue of the gametophyte not involving any triple fusion like in Angiosperms. **Endosperm is a highly nutritive tissue which provides nourishment to the developing embryo.**

In Orchidaceae and Podostemonaceae, the product of double fertilization soon disintegrates and endosperm development is completely suppressed.

Depending upon mode of development three types of endosperm has been recognized:

1. Nuclear endosperm
2. Cellular endosperm
3. Helobial endosperm

Of these nuclear endosperm is the most common type which occurs in about 56% families of Angiosperms. It is followed by cellular endosperm (reported in 25% families of Angiosperms) and then by helobial endosperm (reported in 19% families of Angiosperms).

5.10 POLLINATION

The term pollination means **the transfer of the pollen from the anther to the receptive stigma whether of the same flower or of a different flower.**

Based on the destination of pollen grains, two types of pollinations are there:

(1) **Self-pollination:** If the pollen is transferred from anther to the stigma of the same flower, it is called self pollination or **autogamy** as in pea, wheat and rice.
When the pollen of one flower pollinates the stigma of different flower, but on the same plant, it is called **geitonogamy.**

(2) **Cross-pollination:** If the pollen is transferred from anther to the stigma of the another flower, it is called cross pollination or **allogamy** as in hemp and willow.
Cross pollination within a species (may be inter-varietal) is termed as **xenogamy.**

For self pollination flower must be bisexual (hermaphrodite) and only those bisexual flower which achieve anther dehiscence and receptivity of stigma simultaneously means when anther releases pollen grains then stigma should be ready to receive them. For cross pollination flowers are mostly unisexual. Pollination leads to fertilization and production of seeds and fruits which ensure continuity of plant life.

Agents for pollination

Pollination process can occur by different agencies which can be classified into two categories:

1. Abiotic such as wind (anemophily or anemophilous) and water (hydrophily or hydrophilous) and
2. Biotic such as insects (entomophily or entomophilous), birds (ornithophily or ornithophilous), and bats (cheiropterophily or cheiropterophilous)

Anemophily or anemogamy: Here pollinating agent is wind e.g. in most cereals, poplar, willow, alder, elm, oak, beech, *Urtica*.
Hydrophily or Hydrogamy: Here pollinating agent is water e.g. aquatic plants.
Zoophily or Zoogamy: Again divided into entomophily, ornithophily, and chiropteriphily
Entomophily: Pollinating agents are insects as in *Salvia*, *Ficus*, orchids etc.
Ornithophily: Pollinating agents are birds as in *Bignonia*, silk cotton etc.
Cheiropterophily: Pollinating agents are bats as in *Bauhinia megalandra*, *Eperua falcata* etc.
Pollination ends in a copious dusting of the stigma surface with pollen grains.

5.11 FERTILIZATION

"**Fertilization is the process of fusion of two dissimilar reproductive units, called gametes.**"

In flowering plants, the process of fertilization was first discovered by Strasburger in 1884. The female gametophyte (embryo sac) of Angiosperms is situated in the ovule, at a distance from the stigma. There is no such device developed in the gynoecium (pistil) which facilitates transfer of pollen from stigma to embryo sac. Therefore the pollen after reaching to the stigma produces a pollen tube which facilitates transport of male gametes deep into the embryo sac from stigma.

In Angiosperms, the fertilization is being completed as follows:

Germination of pollen grains and growth of pollen tube

When the pollen is shed from anther it has usually two cells:

1. A generative cell
2. A vegetative cell (tube cell)

The generative cell forms two male gametes. Once the pollen has landed on compatible receptive stigma as a result of pollination, its germination starts. On the surface of stigma the pollen hydrates. This means pollen absorbs water from the surrounding and swells. After that the vegetative cell forms a pollen tube. The stigmatic fluid secreted by the stigma contains sugars, lipids and resins, etc. which provides suitable medium for the germination of pollen grains. Pollen grains as well as pollen tube contain an enzyme cutinase which helps in the penetration of pollen tube into the stigmatic tissue. Cutinase as the name indicates degrades the cutin of the stigma at the point of contact with the pollen tube. The entire content of the pollen including two male gametes of generative cell move into the pollen tube (Fig. 5.15).

The growing pollen tube penetrates the stigmatic tissue and pushes its way through the style and then down the wall of the ovary. The style may be hollow or solid. If it is hollow, then the pollen tube grows along the epidermal surface but in case of solid style, the pollen tube travels through intercellular spaces between the cells which lie in its path.

Entry of pollen tube into ovule

After arriving in the ovary, the pollen tube finds its way into the ovule. The pollen tube may enter into the ovule via three routes (Fig. 5.16).

1. through the micropyle (**porogamy**)
2. through the chalazal end (**chalazogamy)**
3. through the integument (**mesogamy)**

Entry of pollen tube into the embryo sac

It does not matter through which way pollen tube enters into the ovule; it always enters in the embryo sac from the micropylar end means **entry of pollen tube in the embryo sac is irrespective of pollen tube entry into the ovule** (Fig. 5.16).

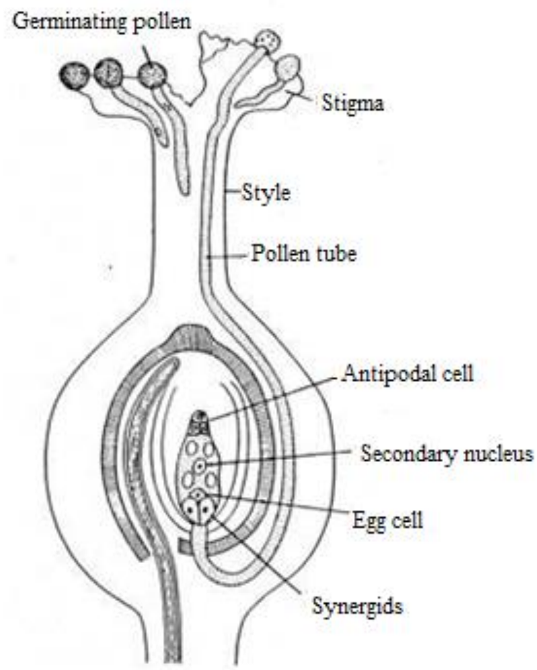
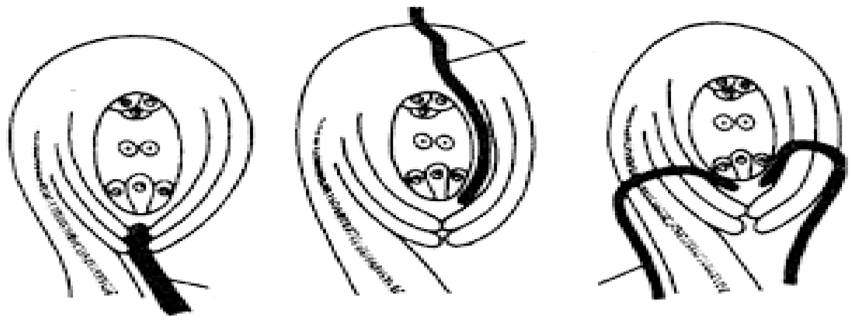


Fig. 5.15: Longitudinal section of a flower showing growth of pollen tube



Porogamy Chalazogamy Mesogamy

Fig. 5.16: Modes of entry of pollen tube into the ovule

Again the entry of pollen tube into the embryo sac after passing micropyle may be via different passages. It may be:

(i) between the egg cell and one of the synergids e.g. *Fagopyrum*

(ii) between the wall of the embryo sac and one or other synergids.er. *Cardiospermum*

(iii) directly penetrates one of the synergids e.g. *Oxalis*

So we can say that synergids not only play an important role in determining the entry of pollen tube in the embryo sac but they also affect dissemination of male gametes in the embryo sac.

Syngamy- fusion of gametes

As the one of the male gametes reached the egg, it fuses with it. As a result of this fusion diploid zygote/oospore (2n) forms (because you know the egg and the male gamete, both are haploid). The fusion of male and female gametes is known as **fertilization**. This is also known as **syngamy**.

One of the most significant discoveries was made by **Strasburger in 1884,** as mentioned above. He observed the actual fusion of the male gamete with the female gamete (egg) in *Monotropa.*

Since two male gametes are released by the pollen tube, what happened to the second male gamete? The answer was provided by **S. G. Nawaschin (1898).** He showed that the one male gamete fused with the egg (syngamy) and the other male gamete with the polar nuclei (triple fusion) while working with *Fritillaria* and *Lilium.* So this was the discovery of double fertilization.

Triple fusion

The other male gamete fuses with the two polar nuclei (or secondary nucleus, if the two have already fused) and so forms triple fusion nucleus (3n), called **primary endosperm nucleus** (Fig. 5.17).

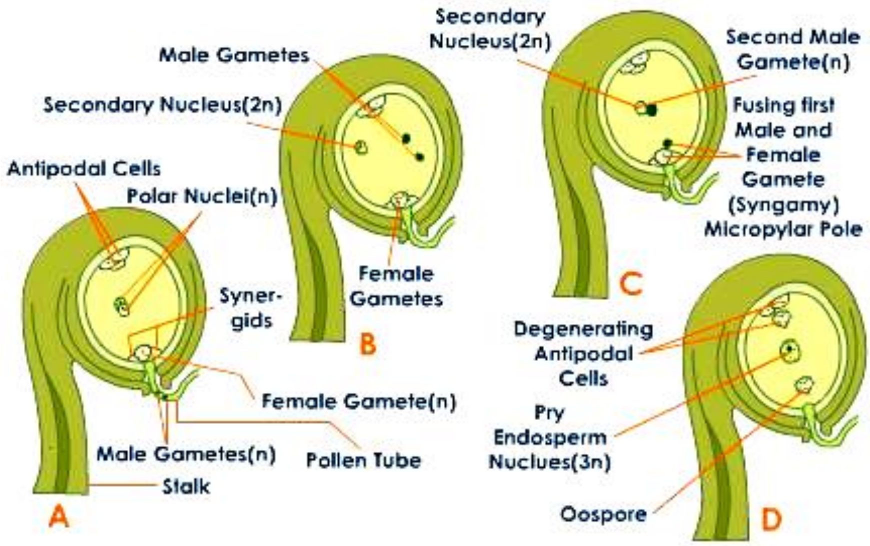


Fig. 5.17: Showing syngamy and triple fusion

Double fertilization

Thus in an embryo sac two sexual fusions occur; one is **syngamy** (i.e. fusion of one male gamete with the egg) and another is **triple fusion** (i.e. fusion of other male gamete with the polar nuclei or secondary nucleus), and therefore, the phenomenon is known as **double fertilization**.

5.12 SUMMARY

Plant body comprises different functions and for this it has different tissue system. For example epidermal tissue system protects inner cells and help in gaseous exchange; ground tissue system performs photosynthesis and the vascular tissue system helps in conduction of water and food. The various types of tissues are classified into three groups - meristematic, permanent and secretary tissues.

Stem is one of two main structural axes of a vascular plant, the other being the root. The stem is normally divided into nodes and internodes: The nodes hold one or more leaves, as well as buds which can grow into branches (with leaves, conifer cones or inflorescence (flowers).

A leaf is an organ of a vascular plant and is the principal lateral appendage of the stem. The leaves and stem together form the shoot. Dicot and monocot plants have different leaf morphology. The leaf of monocot plants is isobilateral and is vertically oriented and the leaf of dicot plants is horizontal and dorsiventrally differentiated.

The megasporangium or ovule consists of nucellus and its protective coats, the integuments. It is attached to the placenta, on the inner wall of ovary by a stalk called funiculus (funicle) and the point of attachment of the body of the ovule to the funiculus is called hilum. On the basis of the position of the micropyle with respect to the funiculus, mature ovule can be classified into six main types. These are: 1. Orthotropous, 2. Anatropous, 3. Campylotropous, 4. Amphitropous, 5. Hemianatropous, 6. Circinotropous.

The female gametophyte (embryo sac) is 7-celled (mostly), 8-nucleate structure having three cells of egg apparatus (two synergid cells and one egg cell) at the micropylar end, three cells (antipodal cells) at the chalazal end and one cell (centre cell) in the centre having two polar nuclei.

The oospore (zygote), formed as a result of fusion of one male gamete with the egg, develops into the embryo while the primary endosperm nucleus- product of triple fusion, develops the endosperm.

The term pollination means the transfer of the pollen from the anther to the receptive stigma whether of the same flower or of a different flower. Based on the destination of pollen grains, two types of pollinations are there: Self-pollination and Cross-pollination.

“Fertilization is the process of fusion of two dissimilar reproductive units, called gametes.” In flowering plants, the process of fertilization was first discovered by Strasburger in 1884. The pollen tube may enter into the ovule via through the micropyle (porogamy), chalazal end (chalazogamy), the integument (mesogamy).

5.13 GLOSSARY

Cambium: A lateral meristem that produces secondary growth

Chalaza: Basal part of the ovule where integument and nucellus connect to the funiculus

Chalazogamy: Entry of pollen tube through the chalazal end

Collenchyma: Tissue composed of unevenly thickened cell walls; collenchyma cells are flexible and support young parts of the plant without hindering growth; collenchyma cells are composed of cellulose

Complex tissue: Tissue that consists of more than one cell type e.g. phloem

Cortex: A primary tissue composed mainly of parenchyma cells, which extends between the epidermis and the vascular tissue

Embryo sac: Female gametophyte located in the nucellus, developed from megaspore

Embryo: A young sporophytic plant while still retain in the gametophyte.

Endarch: A type of xylem maturation in which protoxylem is internal to metaxylem and development proceeds centrifugally (from the inside out)

Endosperm: A nourishing tissue in seed bearing plants that is formed within the embryo sac
Epidermis: The exterior tissue, usually on cell thick, of leaves and young stems and roots
Exarch: A type of xylem maturation in which protoxylem is external to metaxylem and development proceeds centripetally (from the outside in)
Fertilization: Process of fusion of two dissimilar reproductive units, called gametes
Fiber: A long-walled plant cell which is often dead at maturity; fibers impart elasticity, flexibility and tensile strength to plant structure
Funiculus (Funicle): A stalk of the ovule by which it remains attached to the placenta
Gametes: Sexual cells
Gametogenesis: Process of development of gametophyte
Hilum: Region where ovule fuses with funiculus
Integument: The protective covering of nucellus
Intine: Inner thin layer of mature pollen grain
Lamina: The blade of a leaf
Mesogamy: Entry of pollen tube through the integument or funiculus
Mesophyll: The chlorophyll-containing leaf tissue located between the upper and lower epidermis. These cells convert sunlight into usable chemical energy for the plant
Micropyle: Small opening formed by two integuments over nucellus
Midrib: The central rib of a leaf - it is usually continuous with the petiole
Monocot embryo: Embryonical axis having one cotyledon
Monocotyledon: A flowering plant with one cotyledon
Ovule: The megasporangium of seed plant
Parenchyma: the most common type of plant cell; thin-walled cells varying in size, shape, and function
Petiole: A leaf stalk which attaches the leaf to the plant
Phloem: A vascular tissue in land plants primarily responsible for the distribution of sugars and nutrients manufactured in the shoot
Photosynthesis: The process in which plants convert sunlight, water, and carbon dioxide into food energy (sugars and starches), oxygen and water. Chlorophyll or closely-related pigments (substances that color the plant) are essential to the photosynthetic process
Pollination: Transference of pollen grains from anther to stigma
Polyembryony: A condition when more than one embryo is present in a seed
Porogamy: Entry of pollen tube through the micropyle
Primary growth: Growth in length, controlled by the apical meristem
Schlerenchyma: Tissue composed of thick-walled cells containing lignin for strength and support
Secondary growth: Growth in width initiated and maintained by the vascular cambium and cork cambium
Secondary xylem: Xylem produced by the vascular cambium
Sieve cell: A phloem conducting cell type in all vascular plants except Angiosperms

Sieve element: Cell in the phloem tissue concerned with longitudinal conduction of food materials. In flowering plants, it is called a sieve-tube element

Sieve tube: A series of sieve-tube elements arranged end to end and interconnected through sieve plates

Stem: (Also called the axis) the main support of the plant

Synergids : The cells present on either side of egg cell in mature embryo

Tracheid: A water conducting and supportive cell type of xylem composed of long, thin cells with tapered ends and walls hardened with lignin

Triple fusion: A unique feature of flowering plants wherein fusion of one male gamete with the two polar nuclei to form primary endosperm nucleus that give rise to the endosperm

Unitegmic ovule: Ovule with a single integument

Vascular bundle: A strand of tissue composed mostly of xylem and of phloem

Vascular cambium: **A** lateral meristem that produces secondary vascular tissue in stems and roots

Vascular tissue: Tissue composed of conducting cells, i.e. xylem and phloem

Zygote: The fusion product of an egg and a male gamete, i.e. a fertilized egg

5.14 REFERENCES AND SUGGESTED READINGS

- Pandey, S.N. (1997). *Plant Anatomy and Embryology*. Vikas Publishing House Pvt Ltd, New Delhi.
- Singh, V., 2010. *Plant Anatomy and Embryology of Angiosperms*. Global Media Publications, Meerut.
- Singh, V., Pande, P.C. and Jain, D.K. 2012, *Structure Development and Reproduction in Angiosperms*. Rastogi Publications, Meerut.
- Pandey, B. P. (2001). *Plant Anatomy*. S. Chand & Company Ltd., New Delhi.
- Pandey, S.N. (1997). *Plant Anatomy and Embryology*. Vikas Publishing House Pvt Ltd, New Delhi.
- Singh, V. (2010). *Plant Anatomy and Embryology of Angiosperms*. Global Media Publications, Meerut
- Vasishta, P.C. (1968). *Plant Anatomy*. Pradeep Publication & Co., Chandigarh.
- Roy, P. (2010). *Plant Anatomy.* New Central Book Agency, Kolkata.
- Gangulee, H.C., Das, K.S. and C. Datta, C. (1998). *College Botany,* Vol I. New Central Book Agency, Kolkata.
- Bhojwani, S.S., Bhatnagar, S.P. and P. K. Dantu, P.K. (2015). *The Embryology of Angiosperms*. Vikas Publishing House Pvt Ltd, New Delhi.
- Maheshwari, P. (1950). *An Introduction to the Embryology of Angiosperms*. McGraw-Hill, New York.

5.15 TERMINAL QUESTIONS

1. Describe the different types of ovule.
2. Write an essay on types of tissues.

3. Discuss the structure of root.
4. Explain the structure of stem.
5. Write a detailed note on the structure of leaf.
6. Write a short note on (i) embryo sac and its types, (ii) pollination, (iii) fertilization

UNIT -6 PLANT ECOLOGY

Contents:

6.1 OBJECTIVES

After going through this unit students will be able to know:

- about ecology and the branches of ecology
- about the applications of ecology
- about ecosystem and its components
- about various kinds of pollution and pollutants

6.2 INTRODUCTION

The term Ecology was introduced by H. Reiter in 1868, but it was properly defined by Ernst Haeckel, a German Biologist in 1869. The word ecology (old spelling-oekologie) is derived from Greek word, “oikos” meaning house and “logos” meaning the study. Thus, the word ecology literally means the study of living organism in their natural habitat or home. Ecology has been defined by different ecologists. To mention some of them are, by Eudgene Odum (1963) has defined ecology as the study of the structure and the function of nature. Allee et al (1949) considered ecology as ‘the science of inter – relation between living organisms and their environment, including both the physical and biotic environments, and emphasizing inter-species as well as intra species relations’. Taylor (1936) called ecology is the science of all the relations of all organisms to all their environment. According to Charles J. Krebs (1972), Ecology is the scientific study of interactions that determine the distribution and abundance of organisms. Clements Elton (1927) defined it as ‘the scientific natural history concerned with the sociology and economics of animals’. Pinaka (1974) defined ecology as ‘the study of relations between organisms and the totality of the biological and physical factors affecting them or influenced by them’. According to Southwick (1976), Ecology is the scientific study of the relationships of living organisms with each other and with their environment’.

Ecology includes the study of plant and animal populations, plant and animal communities and ecosystems. It was in 1935 that Arthur Tansley, the British ecologist, coined the term ecosystem. Ecosystem simply means ‘ecological systems’. Ecology is defined as the study of ecosystems. Ecologists study the interaction of all the organisms in an ecosystem. Ecosystems describe the web or network of relations among organisms at different scales of organization. Since ecology refers to any form of biodiversity, ecologists research everything from tiny bacteria's role in nutrient recycling to the effects of tropical rainforest on the Earth’s atmosphere.

Ecology deals with numerous and varied components of nature, which can be categorized variously as climate, plants, animals, soil, litter lying over soil, production, dominance, decomposition, diversity etc.

6.3 HISTORY AND BRANCHES OF ECOLOGY

History of Ecology

Although modern ecology developed mainly since 1900, but the ecological ideas were deep rooted into human history. Pre historic man utilized environment information for food, shelter, medicines etc. One of the first ecologists was probably Theophrastus described vivid description of inter-relationships between animals and their environment as early as the 4^{th} century BC (Ramalay, 1940). In the early eighteenth century two schools of thought dominated the growing scientific study of ecology. First, Gilbert White a "Parson-naturalist" is attributed with developing and endorsing the view of Arcadian ecology. Arcadian ecology advocates for a "simple, humble life for man" and a harmonious relationship with man and nature. On the other hand, opposing the Arcadian view is Francis Bacon's ideology 'imperial ecology'. Imperial Ecology believes in the establishment of man's dominance over nature through the exercise of reason and by hard work. Both views continued their rivalry through the early 18^{th} century until Carl Linnaeus's support of imperialism and in short time due to Linnaeus's popularity, imperial ecology became the dominant view within the discipline. Carl Linnaeus, a Swedish naturalist (1707-1778), is well known for his work with taxonomy, the science of naming and classifying organisms. Linnaeus discovered a vast number of plants and animals and recorded them in his book "Systema Naturae". His ideas helped to lay the ground work for modern ecology. Charles Darwin (1859) proposed his theory of evolution and adaptation. According to this theory, organisms change over time because of their inherited traits and characters. Such evolutionary changes are what then allow them to adapt better to their environment. In 1869 Ernst Haeckel coined the term "ecology" since then; ecology became the study of the relationships of organisms with their environment. Eduard Seuss (1875) first defined the term biosphere as the system composed of living organisms and their environment. The plant community in ecology was introduced by Le cog Sendtner and kerner and the animal community introduced by Karl Mobius (1877), Warming (1909), Elements (1916), Cowles (1899), etc.Schroeter and Kirchner (1896) introduced the term Synecology in literature. In 1935 Arthur Tansley coined the term ecosystem as the biological community of interacting organisms and their physical environment. Because of this, ecology became the Science of ecosystems. Eugene Odum and Howard Odum (1953) wrote the first ecology text book and ecology became a University Course.

Andrewartha and Birch, 1954 emphasized the importance of climate and other factors on determing the size of populations. Margolef (1968) has drawan attention to the unifying principles in ecology and considers maturity of ecosystems as measured by diversity and in terms of energetic, 1970's James Lovelock's idea of Gaia, that the whole earth is one living entity and will ensure its own survival even if humans destroy themselves. 1978 conservation Biology established as a discipline focusing on environmental management.

Ecology emerged as a distinct discipline at the turn of the 20^{th} century, and that it gained public prominence in the 1960s; due to wide spread concern for the state of the environment.

From the conventional regional floristic and vegetation studies the switch over to ecosystem approach in the fifties and early sixties. The Science of ecology after undergoing a several hundreds of years gestation period has emerged today as a matured, honoured and scholarly discipline in biological Science.

Prof. Ramdeo Mishra (1908-1998) is revered as father of Ecology in India. His researches laid the foundation for understanding of tropical communities and their succession, environmental responses of plant populations, and productivity and nutrient cycling in tropical forests and grassland ecosystems. Other early ecologists in India were F.R. Bharucha (Royal Institute of Science, Bombay) and G.S. Puri, whose focus was on forest ecology, and who together with Ramdeo Misra founded the International society for Tropical Ecology and the journal, Tropical ecology. F.R. Bharucha introduced the methodology of Zurich- Montpellier school of vegetation analysis in India. We find many references to ecological thought in Indian writings of Vedic, Epic and Pauranic etc. Chakra described the importance of vayu (air and gas), desha (topography), Jata (water), and time in regulation of life. In India, the earliest contributions to modern ecology were made by British ecologists to the forests and grasslands. Our early ecological studies have been influenced by European thought due to the fact that most of the workers were Europeans. The first comprehensive ecological contribution was made by Winfield Dudgeon (1921) who published an ecological account of the upper Gangetic plains employing the concept of seasonal succession therein. This was, elaborated later by Saxton (1922), Mishra (1946, 1958, 1959). Phytosociological analysis of plant communities was for the first time made by Agharkar (1924) mainly for the grasslands. Bharucha and Shankarnarayana (1958) contributed mainly to the Phytosociology of grassland vegetation of Western Ghats using Braun-Blanquet system. Autecological studies on a number of forest trees were made by Pant and Champion (1931), Champion and Griffith (1947), Jagat Singh (1925), and Phadnis (1925). The publication of a book entitled “Indian forest ecology” by G.S. Puri (1960), presents a comprehensive survey of the vegetation and its environment in this sub-continent. Champion and Seth (1965) proposed a detailed classification of Indian vegetation. Autecological and Synecological studies of forest communities have been made by Bhatia (1954, 1955, 1956), Sharma (1955), Puri (1949, 1950), Mohan and Puri (1955, 1956), Arora (1961-1964), Misra and Joshi (1952), Rao (1967). Productivity studies of forests have been made by Misra (1969), Singh (1971), Raman (1970), Sharma (1972), Bandhu (1971), Faruqui (1971) etc.

Branches of Ecology

On the basis of study of organism individually or in group, ecology may be divided mainly in two branches, which are (i) autecology, and (ii) synecology.

In the words of C.F.Harried II (1977), “the two types of study, autecology and synecology are inter-related, the synecologist painting with a broad brush the outline of the picture and autecologist stroking in the finer details”.

Autecology: Autecology is the study of individual species or its population including the effect of other organisms and environmental conditions on every stage of life cycle. This is also called as species ecology. Studies on individual species first started, when human adopted agricultural practices. Misra and Puri (1954) stated that agriculture and silviculture are extensions of autecology. Although, autecology work has been done extensively, still only a few species have been worked out in detail. The important aspects of autecological studies of an individual organism are- Physiology of the plant, Taxonomy and nomenclature of the species, environmental complex (germination, flowering, seed output reproduction capacity, morphology or the plant etc. Prof. R. Mishra and his associates at Banaras Hindu University, Varanasi, has been studied the autecology of several plants.

Synecology: The study of the relationships of plants and animals making up a natural community is known as community ecology or synecology. Synecology is further subdivided into aquatic and terrestrial ecology.

(a) The aquatic ecology includes marine ecology, water ecology, and estuarine ecology.

(b) Terrestrial ecology, subdivided further into areas such as grassland ecology, forest ecology, cropland ecology and desert ecology is concerned with terrestrial (land) ecosystems- their microclimate, soil chemistry, nutrient hydrological cycle and productivity.

Many ecologists have divided ecology into a number of divisions; some of them are as follows-

(i) Paleoecology (Fossil ecology): It deals with the organisms and its relationship with geological environment of the past.

(ii) Cytoecology: It is concerned with the cytological details in a species in relation to populations in different environmental conditions.

(iii) Conservation ecology: It is concerned with the proper management of natural resources such as plant, soil, water, land, mineral resources etc for human welfare.

(iv) Ecological energetics and Production ecology: These modern branches of ecology are still in development stage. These deals with the mechanism and quantity of energy conversions and it flow through organisms, production processes, rate of increase in organic weight in relation to space and time both by green plants and animals.

(v) Space ecology: It deals with the development of partially or completely regenerating ecosystems for supporting life during long space flights.

(vi) Microbial ecology: It is the study of the ecology of microorganisms that live in all natural ecosystems.

(vii) Habitat ecology: It is dependent upon the nature of habitat. It includes grassland ecology, fresh water ecology, marine ecology, desert ecology etc.

(viii) Ecosystem ecology: Organisms obtain energy through photosynthesis or by consuming other organisms. These energy transformations are associated with the movements of materials within and between organisms and the physical environment.

Thus, the interaction between the biotic and abiotic components called an ecosystem is the sub-field of ecology called ecosystem ecology. Issues of interest at this level are how human activities affect food webs, energy flow and global cycling of nutrients.

(ix) Taxonomic ecology: It is the study of organisms belonging to different taxonomic categories and thus the study will be named as bacterial ecology, fungal ecology, algal ecology, insect ecology etc.

6.4 SCOPE OF ECOLOGY

The scope of ecology is huge, and it encompasses all organisms living on earth and their physical and chemical surroundings. For this reason, the field is usually divided into different levels of study including organismal ecology, population ecology, ecosystem ecology and community ecology. Organismal ecology looks at how individuals interact with their environment. Population ecology examines the factors affecting population density and distribution. Community ecology looks at the interactions between the populations. Ecosystem ecology is an extension of organismal, population and community ecology. The ecosystem is composed of all the biotic and abiotic components of that area. An ecosystem biologist examines how nutrients and energy are stored and how they move among organisms and the surrounding atmosphere, soil and water. The scope of ecological study includes:

1-It deals with the study of flow of energy and materials in the environment.

2- It deals with the study of nature and its function.

Taylor (1936), in an attempt to define ecology, has very rightly pointed out that scope of ecology by stating that ecology is the Science of all relations of ecosystem, all organisms to all their environment.

The scope of ecology has expanded considerably as man has become increasingly aware of the problems of the environment. Ecologists have been warn people, of the consequences of the gradual disappearance and destruction of natural resources by humans. With the proper and intelligent knowledge of ecological studies, man may establish a healthy and long lasting balance between the living beings and their environment through ecological studies and management which may solve the many big problems.

Prof. R. Misra (1976) in his address on ecology and development at the ‘All India Symposium on advancement of Ecology at Muzaffarnagar pointed out that potent advance in ecology will accure from the attempts to apply the knowledge to the economic development of India and development of ecological concepts in redressing or reversing the progress of degradation of the environment. The knowledge of ecology is of great help to tackle many of the problems resulting from over exploitation of the resources. There are many subcategories of Ecology. Plant ecology looks at the differences and similarities of various plants in differing climates and habitats. The study of plant in their environment has yielded a large body of knowledge which provides aids to the Science of conservation of natural resources. The knowledge of ecology is being applied in agriculture, food production and horticulture. The International Biological Programme (IBP) was launched since July 1, 1967 to study the biological basis of organic productivity and conservation of natural resources in relation to human welfare.

Bombay Natural History Society (Science-based NGO) has conducted commendable long term ecological studies in the wetlands of Bharatpur, Bhitarkanika, and point Calimer with particular reference to Birds.

The modern ecology revolves round the biological production processes and ecological energetic. Ecology provides scientific basis for resource management.

6.5 ECOSYSTEM

An ecosystem is defined as natural functional ecological unit comprising of living organism and their non-living environment that interact to form a stable self supporting system. The term ecology was coined by Earnst Hackel in 1869 and derived from two Greek words “oikos” meaning house, habitation or place of living and “logos” meaning study.

Ecosystem is a collection of living and non-living entities, all biotic and abiotic organisms are inter dependent on each other for their survival i.e. living organisms cannot live isolated from their non-living environment because the later provides material and energy for the survival of the former. Natural ecosystem has evolved over millions of years manifesting a wide variety of life forms with complimentary interaction and dynamic equilibrium. Human being has manipulated the environment for his gain these manipulation has brought large changes in the ecosystem. It has deviated from natural trends and is losing the equilibrium through evolution and test of time. So, any interruption in the function of any of the factor may disbalance the ecosystem. So there must be a constant interaction between both of them to maintain the stability of ecosystem.

6.5.1 Types of Ecosystem

The kind of organism which can live in a particular ecosystem depends upon their physical and metabolic adaptations to the environment of that place of ecosystem and on certain aspects of the history of our planet, which has determined what organisms have been able to travel where. On earth, there are sets of ecosystems within a geographical region which are exposed to same climatic conditions and having dominant species with a similar life cycle, climatic adaptations and physical structure. This set of ecosystem is called Biome. In the biosphere, there are natural and artificial biomes (ecosystem).

1. Natural ecosystem (Biomes)

Natural ecosystems operate by themselves under natural conditions without any interference by man. Natural ecosystems carry out many public service functions for us. Waste water from houses and industries is often converted to drinkable water by filtration through natural ecosystems, such as soil. Air pollutants from industries and automobiles are often trap on leaves or converted to harmless compound by forests. On the basis of particular type of habitat, they are further sub-divided as

a) Terrestrial Biomes: They are often classified by the vegetation type that dominates the community. The types of vegetation affect the climate and soil structure and that characterize the particular biome. Terrestrial vegetation has a rapid exchange of oxygen, water and carbon dioxide. The carbon dioxide concentration is affected by terrestrial vegetation seasonally and annually. Terrestrial biomes include tropical rain forests, grassland, deserts, cultivated land, etc.

b) Aquatic biomes: They fall into two categories, Fresh water and Marine. Fresh water biomes may be lotic (running water) such as streams, rivers and springs, or lentic (standing water) such as lakes, ponds and swamps, whereas, marine biomes include deep Sea and Oceans.

2. Artificial Ecosystem

They are maintained artificially by man. A pond constructed as a part of a waste water treatment plant is an example of artificial ecosystem, the management can vary over a wide range of actions. Agriculture can be thought of as partial management of certain kind of ecosystem. Here, natural balance is distributed regularly by addition of energy and panned manipulation. For e.g. Wheat maize and rice- fields etc, where man tries to control the biotic community as well as the physiochemical environment. The smallest artificial ecosystem that has been non to sustain a life over long period of time is ‘Folsom bottles’. These materially closed ecosystems were created by Professor Claire Folsom of university of Hawaii by placing water algae, bacteria and sediment from Honolulu bay in a liter flask and sealing the top. The sealed bottles were placed near the window so that some energy is utilized by the biotic components during day time. Some of these have sustained life for nearly twenty years.

Types of ecosystem based on energy resources

Ecosystems are based on two major source of energy, the sun and chemical or nuclear fuels. So, on the basis of the major input, there can be solar powered and fuel powered ecosystems. On the basis of energy resources, the ecosystems are classified as:

1. Unsubsidized natural solar powered ecosystem: In these types of ecosystem, the only source of power/energy is solar energy. For e.g.: ocean, upland forest, grasslands etc.

These are unsubsidized in the sense that there is no auxiliary source of energy available to supplement solar radiation/energy.

2. Naturally subsidized solar powered ecosystem: In these types of ecosystems the main source of energy is sun, which is originated by natural non solar energy. As a result of which extra amount of energy is available to the system that can be used for the production of more organic matter that may be exported to other systems or stored in themselves. The auxiliary natural source of energy may be tides, waves and currents, wind, torrential rains etc.

3. Man subsidized solar powered ecosystem: In these types of ecosystems auxiliary fuels or other energy, like man and machine labor, is supplied by man. Here again, the main source of energy is sun. Examples of these types of ecosystems are agriculture and aquaculture. The power/energy input by man may be in the form of fertilizers, animal power, machine power, sprays etc.

4. Fuel powered ecosystems: In these ecosystems, the sun energy is replaced by highly concentrated potential energy of fuel, chemical or nuclear fuel. Examples of these systems are cities, suburbs, industrial parks, etc. these systems are man's wealth generating and also pollution generating systems. In this system there is no limit of energy input.

6.5.2 Structure

The structure of an ecosystem is basically a description of the organisms and physical features of environment including the amount of description of nutrients in a particular habitat. It also provides information regarding the range of climatic conditions prevailing in the area.

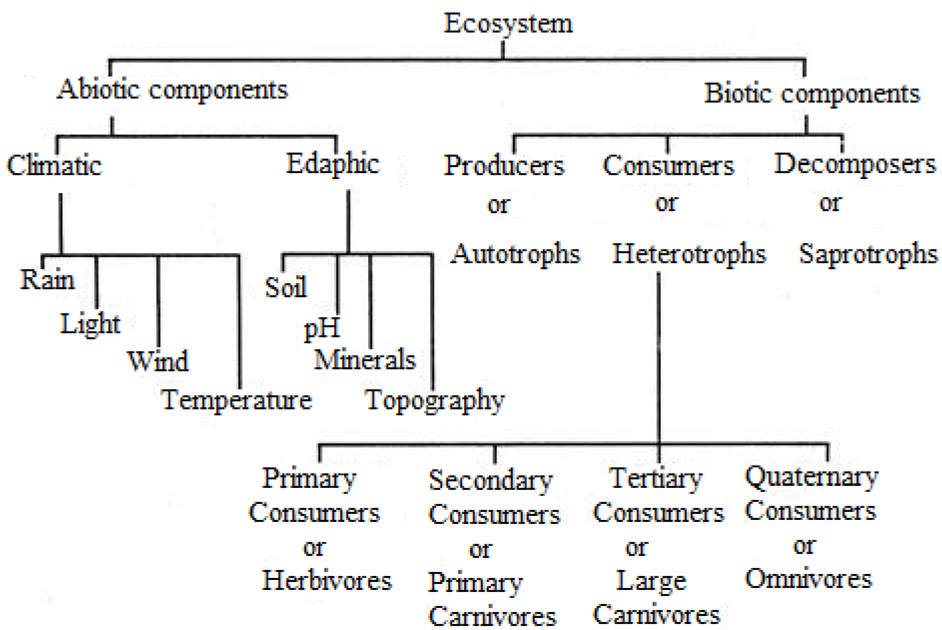


Fig.6.1 Schematic Representation of the Structure of an Ecosystem

6.6 ABIOTIC AND BIOTIC COMPONENTS

Each ecosystem has two main components:

1. Abiotic components: The non living factory or the physical environment prevailing in an ecosystem from the abiotic components. They have a strong influence on the structure, distribution, behavior and inter-relationship of organisms. Abiotic components are mainly of two types:

a. Climatic factors
b. Edaphic factors

The functions of important factors in abiotic components are given below:
Soils are much more complex than simple sediments, they contain a mixture of weathered rock fragments, highly altered soil mineral particles, organic matter, and living organism, soils provide nutrition's, water, a none and a structural organism medium for fragments and organisms. The vegetation found growing on top of a soil is closely linked to this component of

an ecosystem through nutrient cycling. The atmosphere provides organism found within ecosystem with carbon dioxide for photosynthesis and oxygen for respiration. The process of evaporation transpiration and precipitation cycle water b/w the atmosphere and the earth surface.

2- Biotic components:

The living organisms including plants animals and microorganisms (bacteria and fungi) that are present in an ecosystem from the biotic components. On the basis of their role in the ecosystem the biotic component can be classified into three main groups

A. Producers: The green plants have chlorophyll with the help of which they trap solar energy and change it into chemical energy of carbohydrate using simple inorganic compounds using namely water and carbon dioxide. This process is known as photosynthesis as the green plants manufactures their own food they are also known as autotrops. (i.e. auto= self, trophos= feeder). The chemical energy stored by the producer is utilized partially by the producer for their own growth and survival and the remaining is stored in the plants parts for their future use.

B. Consumers: The animal lack chlorophyll and are unable to synthesis their own food. Therefore, they depend on the producers for their food. They are known as hetrotrops. (i.e. htros= other, trophos= feeder). The consumers are of four types, namely

i. Primary consumers or first order consumer or herbivores: these are the animal which feed on plants are the producers, they are called herbivores. Examples are rabbit, deer, goat etc.

ii. Secondary consumer or second order consumer or primary carnivores: the animal which feed on the herbivores is called the primary carnivores. Examples are cats, foxes, snakes etc.

iii. Tertiary consumers or third order consumers: these are large carnivores which feed on secondary consumers. Examples are wolves etc.

iv. Quartinary consumer or forth order consumer or omnivores: these are the largest carnivores which feed on the tertiary consumers and are not eaten by the any other animals. Examples are lions, tigers, etc.

C. Decomposers or reducers: Bacteria and fungi belong to this group. They break down the dead organic materials of producers (plants) and consumer (animals). For there food and release to the environment. The simple organic and inorganic substances produced as by products of their metabolisms. These simple substances are reused by the producers resulting in the cyclic exchange of materials b/w the biotic community and abiotic environment of ecosystem. The decomposers are known as saprotrophos (i.e. sparos= roftn, trophos= feeder).

6.7 POLLUTION ECOLOGY

The term pollution is derived from the latin word “Polluere” which means to defile or contaminate any feature of the environment.

Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, land (soil) and water that can harmfully affect human life or that of other species, our industrial processes, living condition and cultural assets. This definition is based on the report of committee on pollution, National Academy of Sciences, USA 1966.

In simple language, any addition to air, water, soil or food that threatens the health and survival capabilities of humans or other living beings is known as pollution.

According to Southwick (1976), Pollution is the unfavourable alteration of our environment as human activities.

The human population is increasing rapidly with the increase of population; necessities of man are also increasing. Man is exploiting the natural resources for its own interest. Man has disturbed the natural balance and changed the environment of many places to such an extent that they are not suitable for inhabitation by living beings.

According to smith (1927), every human society including rural, urban, industrial and technologically advanced dispose of certain kinds of byproducts and waste products which when injected into the biosphere they affect the normal functioning of ecosystem and have an adversw effect on plants, animals and man are collectively called Pollutants.

In simple language any substance which causes pollution is called Pollutant.

In Environmental Protection Act, 1986 of India, environmental Pollutant means "any solid, liquid, or gaseous substance present in such concentration as may be or tend to be injurious to environment; and the environmental pollution means the presence in the environment of any environmental pollutant"

According to Odum (1971), from the ecological view point, these pollutants can be bio-degradable and non-degradable pollutants.

1-**Non-degradable Pollutants**: The materials that do not degrade or degrade very slowly in the natural environmental conditions are called non-degradable pollutants. Such as- mercurial salts, aluminium cans, DDT and long chain Phenolic chemicals.

2-**Bio-degradable Pollutants**: These pollutants are natural organic compounds which are degraded by biological or microbial action. e.g., domestic sewage, cloth, paper, wood, etc.

In this unit we will discuss about air, noise, water and soil (land) pollution.

6.8 AIR POLLUTION

Air pollution is essential for the existence and survival of humans or other living organisms. No one can survive without air. With the advancement of time air is polluting day by day by human activities or naturally. Air pollution may be defined as the contamination of earth's atmosphere generally resulting from the human activities which adversely offers the living organisms, plants and causes damage to the property. According to the World Health Organization- Air pollution is the presence in the outer atmosphere of substances or contaminants put there by man, in quantities and concentrations and of a duration as to cause any, discomfort to a substantial number of inhabitants of a district of which are injurious to public health or to humans, plant or animal life or property or which interfere with the reasonable comfortable enjoyment of life and property throughout the territories or areas of State. According to Environment Perform Index 2014, India's air quality was among 5 worst nations, smoke, dust, fire, exhaust, gases from motor vehicles etc get mixed up in atmosphere and affects the quality of air.

Air pollution is one of the most dangerous and common kind of environmental problem. Air pollution is the accumulation in the atmosphere of substances that, in sufficient concentrations, endanger human health or produce other measured effects on living matter and other materials.

Air Pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or endanger to humans or other living organisms or cause damage to the natural environment.

There are two types of Pollutants-1) Primary Pollutant and 2) Secondary Pollutant.

1-Primary Pollutant: Primary pollutants are directly released into the atmosphere e.g., CO2, CO are directly emitted from burning of fossil fuel.

The six major types of primary pollutants are nitrogen oxides, hydrocarbons, carbon monoxide, particulates, photochemical oxidants, sulphur dioxide.

a) Sulphur dioxide (SO_2): Sulphur dioxide is originated primarily from the combustion of coal and petroleum. Coal and Petroleum often contain sulphur compounds, and their combustion generates sulphur dioxide. Sulphur dioxide (SO_2) is also released from smelters, oil refineries, fertilizer industries, sulphuric acid manufacturing industries, paper and pulp industries etc.

In the atmosphere, sulphur dioxide reacts with moisture to form sulphuric acid (H_2SO_4) which causes many respiratory diseases and produce acid rainfall over the Earth. Acid rainfall reduces forest growth.

b) Nitrogen oxides (NO_2): Oxides of nitrogen are the second most abundant atmospheric pollutants. Nitrogen oxides are formed when fuel is burnt at very high temperature, such as transportation (automobiles), industrial plants (power). Coal and petroleum often contain sulphur compounds, and their combustion generates sulphur dioxide. Nitrogen oxides contribute to a number of problems as direct exposure to nitrogen oxides irritates the eyes and lungs, poisonous to plant.

c) Carbon monoxide (CO): Carbon monoxide is a colourless, odourless, toxic yet non-irritating gas. Carbon monoxide is an incomplete combustion of fuel such as natural gas, coal and wood and accounts for more than 50 percent of total weight of pollutants added to the atmosphere.

d) Volatile organic compounds: VOCs are organic chemicals, easily vaporize at room temperature, contain the element carbon in their molecular structures, have no colour, taste or smell. They are found in everyday household items such as, craft kits, paints, varnishes, fuels, dry cleaned clothes, pesticides, cigarette smoke, etc.

e) Particulates: Particulate air pollutants may be solid or liquid suspended in a gas, solid particulate air pollutants are heavy metals, pesticides, photochemical smog, smoke, radioactive elements etc. Particulates of liquid nature are liquid aerosols, sprays; some particulates occur naturally, as forest fires, volcanoes, dust storms. Burning of fossils fuels in vehicles, domestic hearths, factory chimneys also generate aerosols.

f) Radioactive Pollutants: A large number of radioactive elements are released in the atmosphere from cooled powder reactors, atomic explosions, testing of nuclear weapons.

2-Secondary Pollutant: Secondary Pollutant is formed in the atmosphere when primary pollutants react or interact. e.g., formation of Peroxy Acetyl Nitrate (PAN-Nitrogen oxides react with unsaturated hydrocarbons and produce Peroxy acetyl nitrate called PAN).

6.8.1 Effects of Air Pollution: Air pollution is harmful to humans, animals and plants.

1) In Plants: The effect of air pollution on plants develops over time chemicals such as fluorides, peroxyacyl nitrate, sulfur dioxide harms the leaves of plants, tissue collapse due to plasmolysis of cells of leaves by air pollution. High concentrations of SO_2 and carbon dioxide lead to chronic injury in plants. Due to air pollution droping of leaves, small fruit formation, stunted growth takes place. NOx and Peroxy acetyl nitrate (PAN) reduces photosynthetic efficiency, damages chloroplast which affects the growth of plant, cause death of forest trees by blocking Hill reaction. Photochemical smog causes damage to plant foliage, severe smog damage to spinach leaf.

2) Effects on humans: Pollutants have a serious effect on human health. Inhaling carbon monoxide combines with the blood hemoglobin and reduces the oxygen carrying capacity of hemoglobin causes headaches, dizziness, hard breathing and irritation of mucous membranes. Lead can damage the brain of young children, Nitrogen dioxide (NO_2). Inhalation causes eye irritation, bronchitis, pulmonary congestion and even causes death. Photochemical oxidant, e.g., ozone causes dryness of mucous membrane of mouth, coughing, irritation in eye, soreness and coughing in chest, pulmonary congestion and eodema, cadmium is poison for respiratory system and causes oxygen deficiency. Particulate air pollution causes respiratory problems worldwide, people suffering from asthma, bronchitis.

3) Effects on Building materials: Air pollution damages building materials. Smoke, dust, fog, grit and oxides of sulphur cause erosion of building materials.SO_2, Nitrogen oxide (NO_X), hydrocarbons formed during combustion of coal and petroleum. They produce acids in the rain water or may remain in the atmosphere. Acid rain corrodes monuments, buildings, furnishing Worldwide famous Taj Mahal is greatly affected by the acid deposition and facing corrosive problem from the SO_2 fumes released from Mathura refinery.

4) Change of climate: Climate change refers to changes in the climate of the earth caused by human activities. Air pollution causes contamination of the upper atmosphere and the change of climate. Ayyar (1973) reported that air pollutant like dust, smoke, CO_2, oxides of N_2 and SO_2 when present in higher concentration causes scattering of light, bringing about climate changes.

Certain gaseous pollutants and aerosols such as ammonium sulphate mists and sulphuric acid mists reach the atmosphere where they have effects on the absorption and penetration of sunlight. The concentration of aerosols, SO_2, ammonium acid fumes affects the pH of rain water.

6.8.2 Ozone layer depletion: The ozone layer is the outer layer of the gas mixture present in the stratosphere, the second layer of the atmosphere. Ozone layer is found between 15 and 35 kms above the surface of the earth. Stratospheric ozone is a naturally occurring gas that filters the Sun's ultraviolet radiation and protects the surface of the earth from the harmful effects of radiation. Ozone absorbs most of the UV radiation of the Sun. The ozone layer is thinning out due to human activities. CFCs (Chloro fluoro carbons) are compounds that consist of chlorine, fluorine and carbon. These gases are used in air conditioners and refrigerators (as coolants), aerosol spray cans, cleaning solvents, fire extinguisher, polyurethane foams. On molecule of CFCs can damage 100,000 molecules of ozone. It was first observed in 1985 over Antarctica that thinning of ozone layer is maximum in spring season and is called ozone hole. Space rockets and planes, supersonic aircrafts also contribute to the destruction of the ozone layer. A diminished ozone layer allows more radiation to reach the Earth's surface. For humans over exposure to UV rays can lead to skin cancer particularly melanoma, cataracts, loss of immunity systems. In plants chlorophyll content is decreased, reduced crop yield interferes with oxygen cycle and affects weather patterns. It damage nucleic acids in living organisms (mutation).

6.8.3 Green House Effect: The green house effect is a natural process that warms the earth's surface. When the solar radiation reaches the earth's atmosphere, some of it is reflected back into space and the rest is absorbed and re-radiated by green house gases. This process keeps the earth warm enough to sustain life. Carbon dioxide, Methane, Nitrous oxide, ozone, CFCs, CO and SO_2 are green house gases. Concentration of CO_2 is increasing due to human activities like burning of fossil fuels, deforestation, agriculture industrial process etc. An increased concentration of CO_2 forms a thick layer and prevents the heat from being reradiated out into space. This thick layer of CO_2 thus functions as a glass panel of green house. Green house is a house of glass used for growing plants that require high temperature for growth. A glass panel of green house allows the sunlight to filter through it but prevents the heat from getting reflected back into space. Similarly an increased concentration of Carbon dioxide and other gases allow the sunlight to filter through but prevent the heat from being re-radiated in outer space. Thus most heat is absorbed by CO_2 layer and water vapours in the atmosphere which is contributing to warming of the earth and causing the earth's temperature to rise. This is so-called Green House Effect. Nearly 100 years ago the atmospheric level of CO_2 was 275 ppm. Presently it is 350 ppm and by the year 2040 it is expected to reach 450 ppm. Enhancement of green house effect results in global warming. Global warming may cause change in weather and climate.

6.8.4 Management control of Air Pollution: Air pollution can be better controlled by Environment management aims at controlling pollution problems and improvement of the atmosphere. To control and reducing air pollution few steps are as follows-

1-Environmental education should be given to everyone.

2-Unleaded gasoline is supplied.

3- Change from high-sulphur coal to low-sulphur coal.

4-Regular pollution control checks on the vehicles.
5-Factories should be situated far from the city.
6-The chimneys of factories should be fitted with filters like cyclone, separators, scrubbers or electric precipitators.
7-Gobar gas for domestic use should be encouraged.
8-For purifying the environment encourage plantation.
9-Non-conventional energy such as solar energy, wind energy should be adopted.
10-Transport systems must have an antismog device.
11- Proper arrangements for recycling of wastes and sewage should be done.
12- Smoking should be banned. It is noticed that there is 50, 00,000 tones tobacco pollution per year.
13-Cyclone collectors and electrostatic precipitators can be used to remove particulate matters.

6.9 NOISE POLLUTION

The word noise is derived from the latin term nausea. It has been defined as unwanted and unpleasant sound. A given sound is pleasant or as unpleasant as noise depends on its loudness and the mood of the person. At times, what is music for someone can be noise for others. But loudness is definitely the most significant criterion which converts sound into noise that causes irritation or annoyance.

Section 2 (a) of the Air (Prevention and control of pollution) Act, 1981 includes noise in definition of 'air pollutant'. Section 2 (a) air pollution means any solid, liquid or gaseous substance including noise present in the atmosphere such concentration as may be tent to injurious to human beings or other living creatures or plants or property or environment.

Noise is that form of sound energy which is unpleasant or undesirable for human ears. Noise pollution causes temporary disruption into the atmosphere. Noise pollution effects on the sense organs, nervous systems, glandular and cardiovascular systems.

Measurement: The frequency of sound is measured in Hertz and the loudness of noise is measured on a logarithmic scale called 'decibel'. Decibel is the basic unit of sound. Noise level above 80 db causes noise pollution. According to National Physical Laboratory, Report that the noise level in India is increasing at the rate of 1db per year. The standard for the measurement of noise is decibel. 60 db is normal conversation. Sounds beyond 80 db are responsible for noise pollution as they become physically painful.

6.9.1 Sources of Noise Pollution: The industrial revolution brought noise pollution.

1- **Industrialization:** Industries uses huge machines which produces a lot of noise during production work. Various industries and big machines working at a very high speed and high noise intensity.
2- **Construction activities:** Construction activities such as road construction and repair, building construction, street work, construction of bridges, dams, flyover, etc. These

construction equipments produce a lot of noise. Buildozers, dump trucks, loaders is a nuisance to the people. The automobile repair shops, blasting, bulldozing, stone crushing etc are other sources of noise pollution.

3- **Transportation:** Different types of road vehicles produce heavy noise. Traffic is the main source of noise pollution in cities. Two wheeler, four wheeler, Trains, Jet planes, horns of engines, pressure horns in automobiles are the major sources of noise. It is very annoying condition. People loose their temperament while driving a vehicle it may cause so many accidental cases.
4- **Household appliances:** Household appliances also make noise and contribute a minor amount of noise. Today's world is a world of gadgets. People use modern domestic gadgets in daily life. Kitchen gadgets such as mixer grinder exhaust fans, pressure cooker, etc. Cleaning gadgets such as vacuum cleaner, washing machine, dish washer etc. For amusement purposes Television, radio, tape recorder etc is used. Air conditioners, coolers, fans etc all these house hold items produce so much noise.
5- **Social events and festivals:** Social gathering or events where loudspeakers, amplifiers or other equipments are used which produce offending noise, fire crackers burst during Diwali, marriages and on other occasions for celebration creates a lot of noise pollution and create disturbances to the patients, students and others.
6- **Loudspeaker:** Loudspeaker is used on every occasion such as marriage, party, birthday, festivals, etc. People play songs on full volume till midnight which is torturous for people living nearby. In religious places such as temples, mosque, gurudwaras, churches and other places loud speaker is frequently used. Hackers play loud noise to attract the attention of people which disturbs the people living nearby.

The various sources of Noise Pollution are industries, traffic noise, thunder storm, building construction, aeroplane, etc. House hold appliances also makes noise and contributes a minor amount of noise as washing machine, pressure cooker, mixer grinder, T.V., vacuum cleaners, cooler, social gathering and social events such as marriage, birthday party. Place of worship where people play the loud speakers on full volume which disturbs the people living nearby. Hackers play loud noise to attract the attention of people. Most of the industries and factories are capable of producing large amount of noise.

6.9.2 Effects of Noise pollution: We hear noise through our ears and continuous exposure to noise level of more than 90db result in the damage of ear drums and impaired hearing. It may be temporary or permanent. Excessive noise pollution can influence psychological health and may reduce the efficiency of work. Noise has a great impact on cardiovascular systems. It causes rise in blood pressure, levels and stress related heart problems. It increases heart beat rate. Constant loud and sharp noise can give severe headache, giddiness and disturb emotional balance. Other health related negative effects of sound pollution are sweating fatigue. Noise pollution affects on pattern. Noise pollution disturbs sleeping pattern and may led to irritation and annoyance and people lose their temper.

6.9.3 Prevention and control of Noise pollution: Noise pollution can be controlled by the following suggestions-

1- Industries or Noise producing factories should be situated far from the cities. Schools and Hospitals should be marked as silent zones.
2- The use of loudspeaker should be banned from 10 pm to 6 am. The banned should be strictly followed.
3- Use sound proofing system where it can be used.
4- Cultivation of thick vegetation may reduce noise pollution.
5- Laws should be implement strictly.
6- Factory workers and traffic controller should use ear muffs, to avoid ear related problems. Specially designed earmuffs can reduce the sound level reaching the ear drum by as much as 40dB.
7- Fire crackers burst during festival and use of loud speakers should be prohibited or at least regulated.
8- Industrial zones should be separated from the residential zones of the city.

6.10 WATER POLLUTION

Water is essential for life. No one can survive without water. Water is one of the greatest natural resources. Water is also facing threats of pollution. Water pollution has reached alarming proportions. Water pollution may be defined as “the adverse change in composition or condition of the water such that it degrades the quality of the water. Water pollution affects the biotic and abiotic factors and its ultimate effect on man remains quite drastic.

6.10.1 Sources of water pollution: Both inorganic or organic or biological substances are responsible for water pollution.

1- Domestic sewage and domestic wastes: Domestic sewage contains kitchen and bathroom, washing and human faecal matter. Discharge of untreated sewage into water bodies are degraded by oxygen requiring microorganisms. Untreated sewage into rivers causes depletion of O2 content. Oxygen depletion causes decreases of algae and clean water fauna may cause floating scums, algal obnoxious blooms. Bacteria and viruses are present in certain sewage wastes which may responsible for water borne diseases such as typhoid, poliomyelitis, amoebic dysentery (loose motions).

2- Industrial wastes: Most of the industrial wastes are into water. Industrial wastes of these industries include mercury, copper, zinc, chlorine, arsenic, and many other toxicants. These industrial chemicals wastes are toxic to animals.

3- **Marine pollution**: Marine pollution is caused by discharge of sewage and rubbish from ships and tankers, oil and petroleum products, pollution of coastal water due to the dumping of domestic and industrial wastes, oil drilling in coastal waters. According to Hunt (1966), oil spills have killed mammals, water birds, vegetation and fish.

4- **Thermal pollution**: Thermal pollution is pollution due to release of excessive amounts of heated water. Thermal pollution may be defined as "the warming up of an aquatic ecosystem to the point where desirable organisms are adversely affected" (Owen, 1885). A large number of industrial plants like coal or oil fired generators thermal, nuclear, atomic etc use cold water for cooling purposes and resultant warmed water has often been discharged into ponds or rivers. Waste heat causes thermal pollution. Thermal pollution causes reduction in DO (dissolved oxygen) content of water which can kill fish and alter food chain composition. It changes the physical and chemical properties of water. With rising temperatures fresh water fauna populations decline and reduce species biodiversity.

6.10.2 Effects of water pollution on the process eutrophication:

Eutrophication (Biological effects): The word eutrophication literally means "well nourished or enriched". According to Hutchinson (1970), Eutrophication is a natural state in ponds and lakes which have a rich supply of nutrients and also occurs as a part of the aging procession ponds and lakes, as nutrients accumulate through natural succession. The process of eutrophication accelerate or speeded up by domestic wastes, industrial wastes, fertilizers, animal wastes, urban drainage, detergents, sediments etc. With the addition of nutrients the growth of micro-organisms and aquatic vegetation increase in large number. Excessive growth of algae occupy the entire area in water causes the phenomenon of water bloom, which produce certain toxins that are responsible for the death of fish, birds and other aquatic animals life. Decomposition of algal bloom leads to oxygen depletion in water due to oxygen depletion aquatic organisms begins to die. Bacterial decomposition of organic wastes too requires oxygen and they with heavy loads the oxygen depletion contents of water may reduce causes below the point where most fish cannot survive.

Effects on humans: Water pollution causes a number of water borne diseases such as jaundice, typhoid, cholera, diarrhea, amoebic dysentery. Arsenic poisoning through water can cause liver and nervous system damage, skin cancer and vascular diseases.

Pesticides: Pesticides in water can damage the nervous system due to the carbonates and organophosphate that they contain. Chlorides can be harmful for reproductive and endocrinal.

Nitrates: Nitrates are dangerous to babies 1) that drink formula milk as it restricts the amount of oxygen that reaches the brain. It causes the "blue baby" syndrome.

2) It causes algae to bloom resulting in eutrophication in surface water.

Lead: Accumulation of lead in the body can damage the central nervous system. Children and women are most at risk.

Fluride: Excess fluorides can cause yellowing of the teeth and damage to the spinal cord.

Chlorinated solvents: These are linked to reproduction disorder and skin cancer. Water pollution could even indirectly affect people through the food chain. Toxic substances that are deposited in water may be consumed by aquatic organisms, such as fish. When people consume contaminated fish some toxic effects are passed on to them.

Arsenic: Arsenic is absorbed through skin and lung. It causes cancer of skin and lung. Chronic exposure to arsenic causes "Black-foot" disease which is prevalent in the parts of West Bengal.

6.10.3 Water pollution control: Proper management of water resources has become the need of today's world.

1- Don't throw litter in the ocean

2- Don't dispose of chemicals, point in water supplies.

3- Tree plantation is very effective to check excessive run off of polluted agricultural water.

4- Proper disposal of municipal sewage so as to avoid contamination of ground water reserves

There are several measures to control water pollution.

A) **Domestic sewage disposal:** Sewage should be properly treated. Proper disposal of domestic sewage is done by using septic tanks, so along pits ad municipal sewage plants. In soaking pits the sewage is discharged into a underground tank. Through the holes of tank sewage water comes out and percolate into the soil and the solid wastes are decomposed by microorganisms inside the tank. In septic tank method sewage is discharged into underground septic tanks through pipes. The solid wastes of the sewage collected at the bottom of the septic tank and it is decomposed by microbes and remaining part of the sewage is drained into the field. In the municipal sewage treatment is done in three stages-primary, secondary and tertiary treatment (advanced). Primary treatment first removes large objects through screening, and then smaller objects such as stones and sand. Remaining suspended solids are settled out in a sedimentation tank. After that the waste water is collected into secondary settling tanks and air current under pressure is passed through the waste water to promote microbial decomposition. In tertiary treatment the water obtained after secondary treatment is subjected to chlorination and testing it is supplies for domestic use.

B) **Disposable of Industrial waste water:** Industrial waste are of two types- Non degradable pollutants such as mercurial salts, cans etc. Biodegradable pollutants- some photochemical substances are added to help in decomposition of these materials when dumped. The biodegradable wastes are disposed through primary, secondary and tertiary treatment.

C) **Effects on Aquatic ecosystem:** Thermal pollution causes reduction in dissolved oxygen, fasten the process of Eutrophication, increase in Biochemical oxygen demand (BOD) indicates intense level of microbial pollution. Thermal pollution causes change in the physical and chemical properties of water, increase in toxicity. The vapour pressure increases, and solubility of gases in water decreases. Aquatic food supply is affected due to rapid setting of sediment load in water.

D) Physiochemical effects of Water Pollution: The pollutants adversely affect the colour, taste and odour of water. Chemically, water contains one part oxygen and two parts hydrogen. The chemical pollution of water causes in alkalinity, acidity, dissolved oxygen in water.

6.11 SOIL POLLUTION

The word soil is derived from a Latin word 'solum' which means earthy material in which plants grow. Soil is the top layer of the earth crust. According to R.F. Daubenmire, "Soil is the upper part of earth crust in which plants are anchored".
Soil may be defined as the upper layer of the unsaturated zone of earth. Soil pollution is defined as "contamination of soil by human activities or other alteration in the natural soil environment".

The upper layer of the earth suitable for vegetation. Geological, climatological and biological factors are very important factors for the process of soil formation. When the physical, chemical and biological properties of soil adversely affected this condition may be known as soil pollution.

6.11.1 Sources of Soil pollution: Following are the sources of soil pollution-

1-Discharge of Industrial waste into the soil: Improper disposal of industrial waste contaminates the soil with harmful chemicals. Wastes from industries such as mercurial salts, cans, DDT, garbage, leather, rubber do not degrade or degrade very slowly. Most industries do require large amount of raw materials to make them into finished products. This requires extraction of minerals from the earth. The extracted minerals can cause soil pollution when spilled on the earth. Whether it is iron ore or coal, the byproducts are contaminated and they are not properly disposed. As a result, the industrial waste lingers in the soil surface and contaminates the soil environment.

2-Agricultural activities: Farmers use an excessive amount of fertilizer on their land to increase crop yields. They use herbicides which kills herbs, insecticides to avoid the damage of crops by pests, fumigants to kill pests of stored products etc. They are synthetic chemicals. Excessive use of these synthetic chemicals has lead to soil pollution. Pesticides are used for pest control. Many of the chemicals are not decomposed and are deposited in soil. As a result, through spraying, run off, rain they mix with water and slowly reduce the fertility of soil.

Pesticides, herbicides are designed chemicals for the control of used pests and unwanted plant growth. Many of pesticides and herbicides have persisted and accumulated in the environment and defile plants and animals.

3-Sewage and domestic waste: Drainage of contaminated surface water into the soil. Sewage sludge contains heavy metals and, if applied in large amounts, the treated soil may accumulate heavy metals and become unable to even support plant life.

4- Acid rain: Air borne SO2 and SO3 react with water or water vapour to form H2SO4. Nitrogen oxides get dissolved into water vapour to form nitric acid. These acids are dissolved in water falling down on earth in the form of rain. This is known as acid rain. The acid rain water reaches on earth and pollutes the soil and adversely affects the productivity of crops.

5- Nuclear explosions: Nuclear explosions release radioactive substances which pollutes the natural quality of soil.

6.11.2 Effects of Soil pollution:

1- **The effects of soil pollution on humans:** Soil pollution is dangerous for human's health. The presence of heavy metals in soil in toxic amounts can cause irreversible developmental damage in children. Excessive exposure to mercury in soil may cause kidney or liver damage. Regular exposures to benzene cause leukemia.
2- **Soil pollution reduce soil fertility:** Excess use of fertilizers and application of toxic chemicals such as pesticides can decrease soil fertility. Thereby and decreasing the soil yield the contaminated soil may produce fruits and vegetables which lacks nutrients and may contain some poisonous substance to cause health problems in human. Crops grown on polluted soil cause health problems on consumption.
3- **Toxic dust:** Emissions of toxic gases from landfills pollute the environment. The unpleasant smell of foul odour causes inconvenience to people.
4- **Effect on plant growth:** Due to the contamination of the soil the balance of ecological system is affected. Mostly plants are unable to adapt to the change in the chemistry of the soil in a short period of time. Bacteria and fungi found in the soil that bind it together begin to decline.

6.11.3 Steps to reduce Soil pollution:

a) **Bioremediation:** Bioremediation is a technique where microorganisms are used to consume the pollution causing compounds and electromechanical systems for extracting chemicals by paving over the trainted area. Use and incite the growth of naturally occurring microorganisms to break down contaminants.
b) **Reuse and Recycle:** The National Science Digital Library NSDL, Reports that reusing and recycling products will help conserve natural resources and save more land from contamination. So glass, khulhad, leaves made should be used. Solid wastes such as plastic, Scrap metal should be recycled and then reused.
c) **Proper solid waste treatment:** To avoid soil pollution waste should be disposed of properly. Acidic and alkaline waste be neutralized before they are disposed of to avoid soil contamination.
d) **Use soil additives:** To maintain soil pH to sustainable levels use soil additives, such as lime and organic matter from composting.
e) **Crop rotation:** Crop rotation is a very effective system than recycling on chemicals. Crop rotation prevents the build up of pests and diseases. It helps to maintain soil fertility and

soil organic matter levels or structure. They ensure that enough nutrients are available to different crops each year.

f) **Organic manure:** Organic fertilizers are derived from human excreta, animal matter, vegetable matter etc.

g) **Public awareness:** Public awareness programs either formal or informal should be introduced.

h) **Ban on Toxic chemicals:** Harmful chemicals and pesticides like DDT, BHC, etc should be banned.

i) **Control acid rain:** To reduce acid rain the emission of chemicals such as nitrogen oxides and sulphur dioxide from industries that cause acid rain should be checked by pollution controlling devices.

6.12 SUMMARY

The term Ecology was introduced by H. Reiter but it was properly defined by Ernst Haeckel. Ecology literally means the study of living organism in their natural habitat or home. Ecology deals with numerous and varied components of nature. On the basis of study of organism individually or in group, ecology may be divided in two branches, which are (i) autecology and (ii) Synecology. The term Autecology denotes ecological studies at the species level while the term synecology denotes ecological studies at the community level. Ecologists have divided ecology into a number of divisions such as Cytoecology, Paleoecology, Conservation Ecology, Ecological energetics and Production ecology, Space ecology, Microbial ecology, Habitat ecology, Ecosystem ecology, Taxonomic ecology. Ecological applications are concerned with the applications of ecological science to environmental problems. Ecology has applications in major areas such as- wildlife management, Soil conservation, Watershed management, Agriculture, Aquaculture, Land utilization, Air pollution, Forestry.

Pollution is a worldwide environmental problem. Pollution includes water, air, noise and soil which adversely effecting the whole environment. It is studied that pollution is increasing day by day due to human activities. Human population and the needs of modern man are increasing but the natural resources are limited. Exploitation of natural resources disturbs the natural balance lead to undesirable change in physical, chemical and biological characteristics of water, air and soil. Any substance that causes pollution is called pollutant. Pollutants can be biodegradable and non-degradable. Air pollution is due to gaseous emissions from factories, automobiles etc which affects the natural quality of air, injurious to environment and living organisms. Noise is that form of sound energy which is undesirable for human ears. Industries, transportation, construction home appliances work etc ate the sources of noise pollution which affects the human psychologically and physically. Water pollution may be defined as the adverse change in the composition or condition of water that it degrades the natural quality of the water. Domestic sewage and domestic waste, industrial waste etc are the sources of water pollution.

Soil pollution may be defined as the contamination of soil by human activities such as farmers' excessive use of chemical fertilizers, improper disposal of industrial waste, acid rain, etc. Soil pollution reduces soil fertility which effects on plant growth, human health and whole environment. Pollution can be controlled by human awareness. Proper waste treatment, reuse and recycle. Ban on toxic chemicals, regular pollution control checks on vehicles, environmental education, plantation etc are some steps to control pollution.

6.13 GLOSSARY

Abiotic components: The non living factory or the physical environment prevailing in an ecosystem from the abiotic components.

Acid Rain: rain water with a pH of less than 4.5

Aquatic: related to water

Autecology: Study of individual organism or species in relation to its environment.

Biodiversity: Biodiversity refers to the variety of life on Earth.

Bioremediation: a process using organisms to remove or neutralise contaminants (e.g. petrol), mostly in soil or water.

Biotic: Living; usually applied to the biological aspects of an organism's environment, i.e. the influence of other organisms (opposite of abiotic).

BOD Biological oxygen demand: a chemical procedure for determining how fast biological organisms use up oxygen in a body of water.

Chlorofluorocarbons: Chemicals which are responsible for green house effect and ozone layer depletion.

Ecology: Study of interaction between living things and their environment.

Ecosystem: An ecosystem includes all of the living things (plants, animals and organisms) in a given area, interacting with each other, and also with their non-living environments (weather, earth, sun, soil, climate, atmosphere).

Eutrophication: Lowering of dissolved oxygen concentration due to release of large amounts of phosphate, nitrate and organic matter into water.

Green house effect: increase in earth's temperature due to high concentration of CO_2 in the atmosphere results in trapping of heat within the earth's atmosphere.

Habitat: a specific place or natural conditions in which a plant or animals lives

Microclimate: A *microclimate* is a smaller area within a general climate zone that has its own unique climate.

Pollutant: Substance that causes pollution

Sewage: Wastes including solid or liquid from houses and industries

Succession: Succession refers to a directional, predictable change in community structure over time (Grime 1979, Huston & Smith 1987).

Synecology: study of relations between natural communities and their environments.

Taxonomy: The science of naming and classifying organisms.

Terrestrial: related to land
Thermal pollution: Pollution due to release of excessive amounts of heated water

6.14 SELF ASSESSMENT QUESTION

6.14.1 Objective type Questions:

1-Term ecology was proposed by-
(a) Taylor (b) Odum
(c) Haeckel (d) Reiter

2- The term ecosystem was coined by-
(a) Tansley (b) Warming
(c) Reiter (d) Dorwin

3-Who reversed as father of ecology in India
(a) Ramdeo Mishra (b) Pant
(c) Bhatia (d) Mohan

4-Two main branches of ecology-
(a) Autecology and Genecology (b) Genecology and Synecology
(c) Autecology and Synecology (d) None

5-Synecology is the study of-
(a) Individual (b) Communities
(c) Study of environment (d) None

6-Theory of evolution and adaptation is proposed by-
(a) Charles Darwin (b) Linnaeus
(c) Theophrastus (d) Eugene Odum

7-The book "Systema Naturae" is written by-
(a) Eduard Seuss (b) Linnaeus
(c) Shelford (d) Francis Bacon

8-Autecology refers to-
(a) Study of individual species (b) Study of different species
(c) Study of environment (d) Both (a) and (b)

9-The term Ecology was properly defined by-
(a) Linnaeus (b) Ernst Haeckel

(c) Gilbert white (d) Howard Odum

10-The book "Indian Forest Ecology" is written by-
(a) G.S.Puri (b) Champion
(c) Bandhu (d) Faruqui

11- Which one of the following is Non-degradable pollutant:
(a) Domestic sewage (b) Cloth
(c) Paper (d) DDT

12- Which one of the following is responsible for the depletion of ozone layer:
(a) Methane (b) Carbon dioxide
(c) Chlorofluorocarbon (d) Ethane

13- Indication of decreased BOD is:
(a) High CO_2 contents (b) High O_2 contents
(c) High microbial activity (d) Low microbial activity

14- Acid rain is caused by:
(a) SO_2 (b) SO_2 and CO
(c) Phosphates (d) All of these

15- What is the intensity of sound in normal conversation?
(a) 90 (b) 60
(c) 150 (d) 20

Answers Key: **1**. d, **2**. a, **3.** a, **4.** c, **5.** b, **6.** a, **7.** b, **8.** a, **9.** b, **10.** a, **11.** d, **12.** c, **13.** d, **14.** a, **15.** b.

6.15 REFERENCES

- S.K. Agarwal, Fundamentals of Ecology, APH Publishing Corporation, New Delhi
- Dr. R.S, Shukla and Dr. P.S.Chandel , A Textbook of Plant Ecology including Ethnobotany and Soil Science, S.Chand and company Pvt., LTD, Ramnagar, New Delhi
- Prof. P.R.Trivedi, Ecology and Environment, APH Publishing Corporation, New Delhi
- Sharma, P.D. 2005**.** Ecology and Environment. Rastogi Publication
- Shukla R.S. and P.S. Chandel (2014), A Text Book of Plant Ecology, S. Chand and company Publication, New Delhi

- Sundara Rajan S. 2013, College Botany (Vol.-2), Himalaya Publishing House, Mumbai
- Singh H.R. (2014), Environmental Biology, S. Chand and company Publication, New Delhi
- Khitoliya R.K. (2014), Environmental Pollution, S. Chand and company Publication, New Delhi
- B.P. Pandey.(2007), Botany for Degree students, S. Chand and company Publication.
- *www.benefits-of-recycling.com/**pollution ecology**/*
- *en.wikipedia.org/wiki/**Pollution***
- *en.wikipedia.org/wiki/**Air pollution***
- *en.wikipedia.org/wiki/**Water pollution***
- *en.wikipedia.org/wiki/**Soil contamination***
- Ambasht. R.S. (1990) , A text book of Plant Ecology

6.16 SUGGESTED READINGS

- Fundamentals of Ecology by S.K. Agarwal.
- A Textbook of Plant Ecology including Ethnobotany and Soil Science by Dr. R.S, Shukla and Dr. P.S.Chandel,
- Ecology and Environment by Prof. P.R.Trivedi
- Ecology and Environment by P.D. Sharma
- A text book of Plant Ecology by Dr. R.S.Shukla and Dr. P.S. Chandel (S. Chand and company Publication)
- Concepts of Modern Ecology by S.C.Tewari (Bishen Singh, Mahendra Pal Singh, Dehradun)
- Plant Ecology by P.D.Sharma.

6.17 TERMINAL QUESTIONS

1- Define the term Ecology and discuss about the history of ecology?

2-Describe the applications of ecology.

3- Write the detail account on different branches of ecology?

4-Explain the following terms:

(a) Synecology

(b) Autecology

5-Define Pollution. Explain different types of Pollution.

6-Give a brief account of Water Pollution.

7-What is air pollution? Describe the causes and control of it.

8-Write short notes on the following:

(a) Pollutants of air

(b) Soil pollution

UNIT 7- PLANT PHYSIOLOGY AND BIOCHEMISTRY

Contents:

7.1 OBJECTIVES

After reading this unit students will be able to-

- Understand the significance and mechanism of photosynthesis.
- Understand the significance and mechanism of respiration.
- To understand the structure and classification of carbohydrates.
- To understand the structure and classification of lipids.
- To study physical and chemical properties of proteins.
- Explain the basic concept of enzyme and its type.

7.2 INTRODUCTION

The autotrophic plants synthesize enormous amounts of organic food with the help of the light energy available from Sun. Carbohydrates produced through photosynthesis constitute the basic raw materials, which directly or indirectly give rise to all the organic components of virtually all plants and animals. The entire humanity depends upon the prepared food of plants. Every year some 200 billion tons of carbon go through the photosynthetic process. It is one of the most massive chemical events going on the earth. It has been estimated that plants take up 7 x 10^{11} tons of CO_2 to produce roughly 5 x 10^{11} tons of solid plant material. Approximately 90 per cent of the world's photosynthesis is carried out of marine and freshwater algae.

Photosynthesis is a crucial energy converting process by which plants produce molecular oxygen and carbohydrates by the use of photons present in the light. The natural source of light, the Sun, helps the green colored plants to fix the atmospheric carbon dioxide into usable molecular oxygen that we humans happen to breathe.

They help in maintaining a balanced level of oxygen and carbon dioxide in the atmosphere. Almost all the oxygen present in the atmosphere can be attributed to the process of photosynthesis, which also means that respiration and photosynthesis go together. Also, the chemical energy stored in plants is transferred to animal and humans when they consume plant matter. Photosynthesis can therefore be considered the ultimate source of life for nearly all plants and animals by providing the source of energy that drives all their metabolic processes.

Often, the respiration is masked by the fact that photosynthesis produces oxygen faster than respiration takes it up and photosynthesis uses carbon dioxide faster than respiration produces it. It is only in the dark that the full effects of respiration become apparent when photosynthesis is brought to a halt.

Plants need energy to take in mineral salts from the soil where they are present in very low concentration - this needs work (energy) to concentrate the mineral inside the plant. Plants growing in waterlogged soils (which are short of oxygen) cannot respire in their roots and soon show the symptoms of shortage of minerals (like yellow leaves). (Rice is interesting because it has a pithy stem through which it enables oxygen from above the water to get down to the roots and therefore rice thrives in "paddy fields".)

Respiration is one of the many processes needed for survival. It is the process by which energy is released from food by oxidizing the organic molecules. Respiration may occur in the presence of oxygen, in which case it is called aerobic respiration or it may occur in the absence of oxygen and is called anaerobic respiration. The main organic molecules used in respiration are carbohydrates, such as the monosaccharide glucose and fructose, and fats. Proteins may also be oxidized however it is a secondary source as protein is needed for other things such as cell growth and repair.

7.3 PHOTOSYNTHETIC PIGMENTS

The Photosynthetic products are energy rich organic compounds. The potential chemical energy of these compounds comes from the light energy.
The light energy to be effective in photosynthesis must be absorbed by a suitable pigment. This vital role is performed by the green pigment, chlorophylls, in plants.

7.3.1 Chlorophyll

There are at least seven types of chlorophylls known: **chlorophylls a, b, c, d** and **e**, **bacteriochlorophyll** and **bacterioviridin.** All these chlorophyll molecules contain a tetrapyrrole skeleton formed into a ring with an atom of magnesium in the centre of the ring. A so-called pyrrole molecule contains a skeleton of five atoms, four of carbon and one nitrogen and the five are arranged in a ring. Four such pyrroles arranged in a ring form the head of a chlorophyll molecule. Attached to this porphyrin ring at one point is an alcohol (phytol) “tail”, a long chain of linked carbons. Relatively minor variations in the kinds and groupings of other atoms joined to this head and tail skeleton account for the differences among different kinds of chlorophylls.

Chlorophylls ‘a’ and ‘b’ are the two most abundant chlorophylls. Chlorophyll a is found in all the autotrophic plants except the photosynthetic bacteria. Chlorophyll b is absent in the blue green, brown and red algae. The other chlorophylls c, d, e are found only in algae and in combination with chlorophyll a. Chlorophyll a possess –CH3 , a methyl group which is replaced by –CHO, an aldehyde group in chlorophyll b. The structures of chlorophyll a, chlorophyll b and bacteriochlorophyll are given in Fig.5.1.
The molecular formulae of the chlorophylls are given below:
Chlorophyll a : $C_{55}H_{72}O_5N_4Mg$
Chlorophyll b : $C_{55}H_{70}O_6N_4Mg$

Both the chlorophylls a and b have hydrophilic Mg – Porphyrin head and a lipophilic phytol tail.

The chlorophylls are primarily located within the grana thylakoids. The chlorophyll molecules form a monolayer between the protein and lipid layers of the membranes of the thylakoids. The hydrophilic heads of the chlorophyll molecules are embedded within the protein layer while the lipophilic tails are located within the lipid layer.

7.3.2 The Absorption Spectrum

The portion of the electromagnetic spectrum which participates in photosynthesis is from 300 to 900 nm. In green plants only the visible spectrum (400-750 nm) is effective in photosynthesis. Photosynthetic green bacteria can absorb wavelengths from 375-800 nm while purple photosynthetic bacteria absorb 300 to 950 nm.

The chlorophyll pigments chiefly absorb in the violet blue and red parts of the spectrum. The absorption band in the violet blue region is called Soret band.

The chlorophyll a has two prominent absorption peaks at 430 nm and 662 nm. There are reports of different forms of chlorophyll a with absorption peaks at 660, 670, 680, 685, 690 and 695 to 720 nanometers. These variations are perhaps due to the environmental changes. The absorption peaks for chlorophyll b occur at 453 and 642 nm.

7.3.4 Carotenoids

The carotenoids are the main accessory pigments in photosynthesis. They transfer the light energy to chlorophyll for photosynthesis. The carotenoids are widely distributed in plants. They occur in bacteria, algae and higher plants. They include orange carotenes and yellow xanthophylls. They absorb wavelength 400 nm to 500 nm because of which they are orange in colour. Of the carotenes β-carotene is the abundant type. It absorbs blue light, and, therefore, appears yellow in colour. ά-carotene is present in very small amounts in certain species. The carotenoids perform two types of functions in the green plants. They trap light energy and transfer it to the chlorophyll a particularly in algae and to some extent in higher plants. In higher plants this function is performed by lutein of the xanthophylls and β-carotene.

At high light intensities the entire cell apparatus is oxidized by atmospheric oxygen into carbon dioxide. This process is termed photo oxidation which is as good as combustion. The carotenoids (β-carotene) protect the photosynthetic apparatus from this type of destruction by trapping and dissipating the excess excitation energy which would have otherwise converted molecular oxygen to a highly reactive and mutagenic superoxide O_2. The dissipation of excess energy in the form of heat is facilitated by xanthophylls cycle.

The carotenes are hydrocarbons i.e. they contain carbon and hydrogen. The xanthophylls (also known as carotenols) are alcohols and ketones and contain oxygen, carbon and hydrogen. Like chlorophylls they are located in chloroplasts and also in chromoplasts. Carotenes are named after carrot in which they are abundant.

5.5.4 Phycobilins

Englemann found blue green light to be very effective in increasing the rate of photosynthesis of brown and red algae. In fact the red algae gave the best result in green light. Since chlorophylls hardly absorb green light it became obvious that some other accessory pigment was involved. Several workers have since then demonstrated the role of phycobilins and carotenoids in photosynthesis. The irradiation of carotenoids causes fluorescence of chlorophyll suggesting the transfer of energy by accessory pigments to chlorophyll a during photosynthesis.

In blue-green and red algae some additional pigments known as phycobilins are present. They are also tetrapyrroles like chlorophylls but the four joined pyrrole rings form a straight chain. Like anthocyanins they also mask the green color of the chlorophylls. They are, however, intimately associated with the cholorophylls. The light absorbed by them can be used in photosynthesis. Phycobilins include red coloured phycoerythrins and blue coloured phycocyanins found in red and blue-green algae respectively.

5.5.5 Anthocyanins

The colour of leaves is modified in certain plants due to the presence of purple pigment called anthocyanins. They are formed by several rings of atoms, the rings being joined in complex ways. Anthocyanins are soluble in water; hence they occur in the vacuolar sap of the cells. This pigment does not take any part in photosynthesis. Anthocyanin is not present in the cytoplasm.

7.4 CONCEPT OF TWO PHOTOSYSTEMS

There are two reactions involved in photosynthesis. The first reaction requires light and is called the light or Hill reaction. The second reaction does not require light and is called the dark or Blackman reaction.

1. The light reaction is a photochemical reaction, while the dark reaction is a thermochemical reaction. The unit of photosynthesis is believed to consist of two types of centres, photosystem I and photosystem II. These are excited at different wavelengths of light. The two systems are linked by redox catalysts. The light reaction involves two processes, photophosphorylation and photolysis of water. In photophosphorylation there is conversion of light energy into chemical energy. Photophosphorylation is of two types, cyclic photophosphorylation and noncyclic photophosphorylation.

2. The dark reaction takes place through a series of steps known as the Calvin-Benson cycle. The details of different stages of photosynthesis will now be taken up. In higher plants and algae two pigment systems are involved in photophosphorylation. These are called photosystems I and II. The pigments of the two systems are known as pigment system I (PS I) and pigment system II

(PS II), respectively. PS I and PS II are structurally distinct. PS I and PS II both contain chlorophyll a, chlorophyll b and carotenoids. The distribution of the two pigments however, varies in the two systems. PS I contain more carotenes than PS II. Xanthophyll predominates in PS II. The primary photosynthetic pigment of both systems is chlorophyll a. In blue-green and red algae phycobiliproteins (formerly phycoerythrin and phycocyanin) are present as accessory pigments.

5.6.1 The Photosynthetic Apparatus

The membranes of the thylakoids are the seat for the light reactions of photosynthesis. The reactions are accomplished with the involvement of a large variety of proteins. They are all intrinisic proteins. They project on one side into the lumen of the thylakoid and on the other side into the stroma. They include some of the enzymes of the electron transport chain, the reaction centres and the antenna pigment protein complexes. The chlorophylls and carotenoids are linked to these proteins in a highly specific manner. Fig.5.5 shows the organization of the protein complexes within the membranes of the thylakoids. Park and sane (1971) assumed that the stromal lamellae has PS I whereas granal lamellae has both PS I and PS II. The stromal lamella can carry on cyclic photophosphorylation while the granal lamellae carry on the non cyclic photophosphorylatioin. The PS II occurs in the appressed region of grana thylakoids and PS I occurs in the stroma thyakoids and non-appressed regions of grana thylakoids.

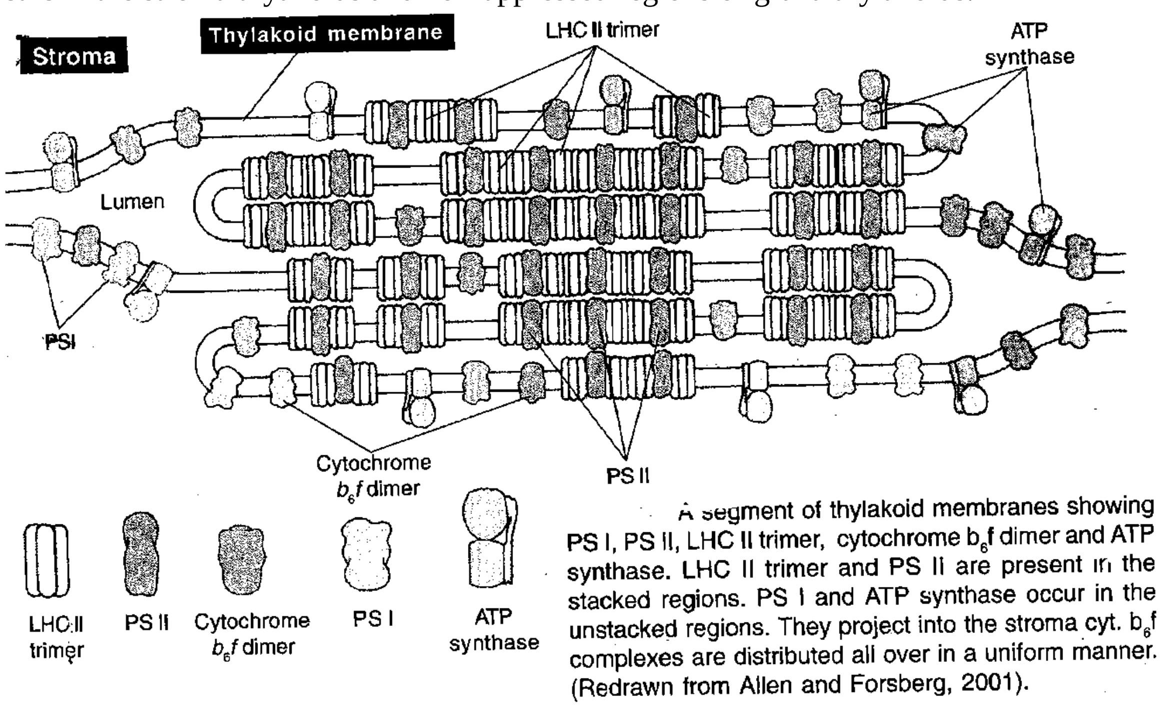


Fig. 7.1 A segment of thylakoid membranes

Anderson and Anderson (1988) have reported that PS II reaction center and antenna chlorophylls as well as electron transport proteins are concentrated in the stacked regions of grana lamellae. The PS I reaction center, its associated antenna pigments, electron transfer proteins as well as

ATP synthase occur only in the stroma lamellae and at the edges of the grana lamellae. The cytochrome b_6f complex of the electron transport chain are present all over the grana and stroma lamellae. The electron carriers are placed in such a manner that they transfer the electron lost by PS II in the grana to the stroma region where PS I is situated.

PS II is present in large amount in the thylakoids of grana. The ration of PS II and PS I has been found to be 1.5:1 in majority of the species. The PS I is, however, in plently in cyanobacteria and the cells of the bundle sheath of C_4 plants.

7.5 PHOTOPHOSPHORYLATION

There are two types of phtophosphorylations in the chloroplasts of plants:
1. Non cyclic photophosphorylation
2. Cyclic photophosphorylation.

1. Non-Cyclic Photophosphorylation

The famous Z scheme of non-cyclic phtophosphorylation was developed as a result of work of several research workers. According to Hill and Bendall (1960), Rabinowithch and Govindjee (1965) and others the photochemical reactions occur in series, the product of one being used up by the other. It has undergone modifications from time due to discovery of new electron carriers.

When the chlorophyll is photoexcited the electron gets dislodged from the chlorophyll molecule leaving a 'hole' in it. The 'hole' left by displaced electron is soon filled up by the return of the same electron or another one (cyclic and non-cyclic electron transport). In pigment system I there are 200 chlorophyll a molecules and just one P700 molecule. Any one or all of the chlorophyll a molecules can absorb red or blue photons of light and can pass on the excitation energy to P700 molecule which alone can lose the electron. Due to very tight arrangement of the chlorophyll a 683 molecules within PS I the singlet excitation energy resulting from the absorption of a light quantum by Chl a 683 migrates from one molecule to another by resonance transfer until it reaches a chlorophyll a 683 molecule which is adjacent to the long wave absorbing pigment (P700). The energy is then passed as an excitation to the P700 molecule which is the reaction centre. P700 attains the first excited singlet state and loses an electron to an electron acceptor. The PSI function has been compared to an antenna which causes the 'funneling' of photons into an 'energy trap' or 'sink' (P700) or to a lens which concentrates light into a focal point (P700).

The sequential steps in the electron transport chain are discussed under the following headings:

a) **PS II AND Photolysis of water:** One of the two primary photochemical reactions in photosynthesis is the absorption of red light by PS II. According to Barber et al. (1999) PS II is a multi subunit protein super complex which has two unique chlorophyll a P680 reaction centers (dimer) and some antenna complexes. After receiving light the P680 reaction center gets photoexcited as a result of which an electron is ejected. The excited form of P680 known as P680* loses its electron to pheophytin, which is the primary electron acceptor. Pheophytin is a type of chlorophyll a in which magnesium is substituted by two hydrogens. According to Okamura et al. (2000) the electron is transferred from pheophytin to plastoquinones Q_A and then to Q_B. The two are bound to the reaction center. The second plastoquinone Q_B after receiving two electrons is reduced to Q_B-^{2} which reacts with two protons of the stroma to form QH_2 (plastohydroquinone). QH_2 which is a small nonpolar molecule was earlier bound to PS II is freed from it. It moves into the non-polar part of the phospholipids and transfers the electrons to cytochrome b_6f complex. (Fig 5.6)

b) **The Cytochrome Complex:** The cytochrome b_6f complex is also a large multi subunit protein. It has many prosthetic groups. There are two b type hemes. a c type heme (cytochrome f), and a Rieske iron sulphur protein (FeSr) present in the complex.

In the non-cyclic or linear type of electron transfer QH_2 transfers one electron to Rieske FeS protein which is present on the side of the lumen and transfers another electron to one or the cytochrome b. The Rieske FeS protein transfers its electron to cytochrome f, which is also present on the lumelal side of the thylakoid membrane. In the process two H^+ ions are released into the lumen.

In another mechanism for the transfer of protons and electrons in the cytochrome b_6f complex, called cyclic process, the other QH_2 electron received by cytochrome b is transferred which after passing through the two b type cytoquinone reduces the semiquinone to plastohydroquinone. In the process two protons are taken up from the stroma so that a total of 4 protons are released in the lumen (Fig 5.6).

c) **Plastocyanin, the Electron Donor to PS I:** The plastocyanin accepts electrons from cytochrome b_6f complex and donates them to PS I. It is the only copper containing electron carrier in the electron transport chain of photosynthesis. It is a small water soluble protein and is present on the side of the lumen. Plastocyanin does not appear to be indispensable since in some algae non-cylic electron transport chain occurs even in its absence.

d) The PS I: According to Jordan *et al.*, the PS I is also a large multi subunit complex. It contains not only the reaction center P700 but also a number of components which participate in the transfer of electrons. They are all present around two big sized proteins called PsA and PsB and some small proteins. The P700 is positioned in such a manner in the membrane that the electron is easily ejected. The primary electron acceptor is A_0 which is a type of chlorophyll. The next electron acceptor is A1 which is a quinone. The electron is then transferred to soluble ferredoxin (Fd) through a series of iron sulphur proteins namely Fe Sx, Fe SA and Fe SB.

The electrons far transferred from ferredoxin to ferredoxin-$NADP^+$ reductase (FNR) which donates them to $NADP^+$ to produce NADPH (Vishniac and Ochoa, 1951).

e) The ATP Synthase: It is a large complex enzyme and is known by several names such as ATPase, the coupling factor, and CF_0-CF_{1*} This enzyme is situated only at the edges of granal thylakoids and in the stroma lamella and therefore, the protons coming from photolysis of H_2O

and from cytochrome b_6f complex have to move great distances laterally to reach it. One of the two components of the enzyme called CF_0 is hydrophobic and is bound to the membrane. The other component termed CF_1 projects into the stroma.

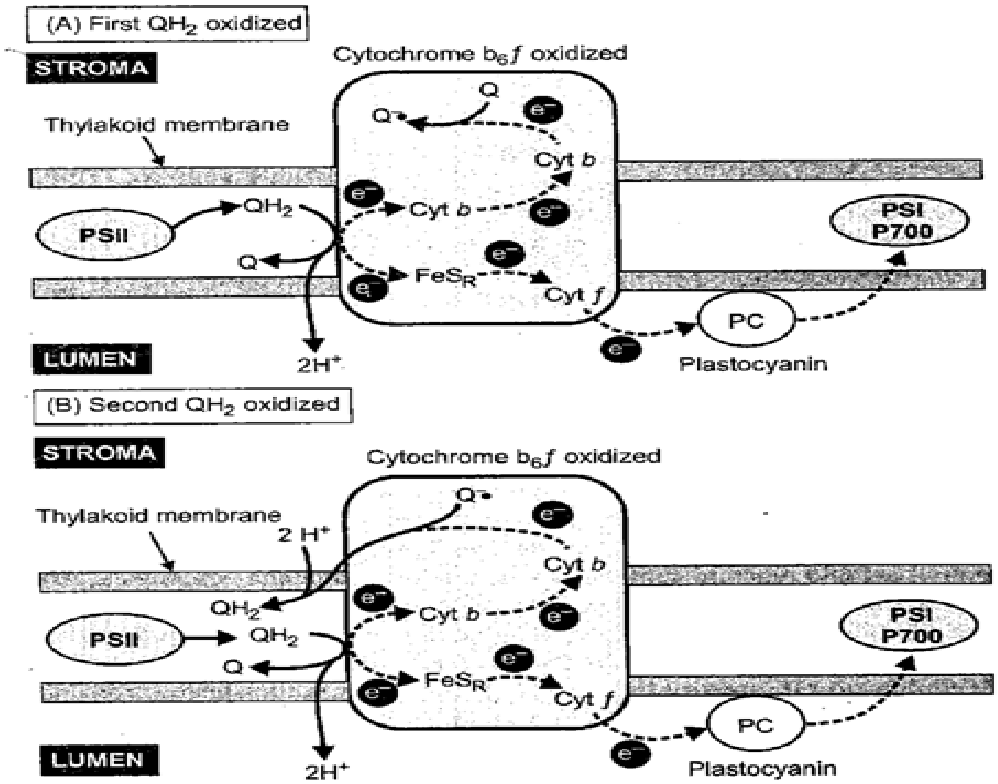


Fig. 7.2 Diagram to show the non-cyclic type of electron transport in the cytochrome b_6f complex. A. Linear or cyclic transport; B. Cyclic transport (Redrawn from Taiz and Zeiger, 2002)

According to Peter Mitchell's chemiosmotic theory the energy required for the synthesis of ATP is provided by proton motive force. The proton motive force is created by the proton chemical potential and the transmembrane electrical potential. The H^+ ions released during photolysis of water accumulate in the lumen of the thylaoids.. The accumulated H^+ ions in the lumen try to leak back into the stroma through the ATP synthase. The protons enter the channel formed by CF_0 and when they cross through the catalytic sites of β-polypeptide of CF_1, the proton motive force breaks, releases energy as a result of which ATP is generated. The latest detailed Z scheme is given in Fig. 7.3.

2. Cyclic Photophosphorylation

Another type of photophosphorylation can also take place under certain conditions e.g. when the amount of available $NADP^+$ is low or PS II is absent or monochromatic light beyond 680 nm is given to the plant in the laboratory. This process involves only pigment system I and, therefore, photolysis of water and the consequent evolution of oxygen does not take place. Non cyclic electron transfer does not take place and NADPH is not formed. The CO_2 assimilation is retarded (red drop). The photosynthetic enhancement can, however, take place if PS II wavelength of light is also given to bring into action the noncyclic phtophosphorylation.

In cyclic electron transfer the electron flows from photoexcited P700 to X, A and B, FRS and then to ferredoxin, which unable to pass electrons to $NADP^+$ transfers them to cytochrome b_6 (E^0 = - 0.06 V). The electron is ultimately cycled back to P700 via PQ, FeS, cytochrome f and plastocyanin. ATP molecule is formed either between ferredoxin and cytochrome b_6 or between cytochrome b_6 and cytochrome f or at both steps.

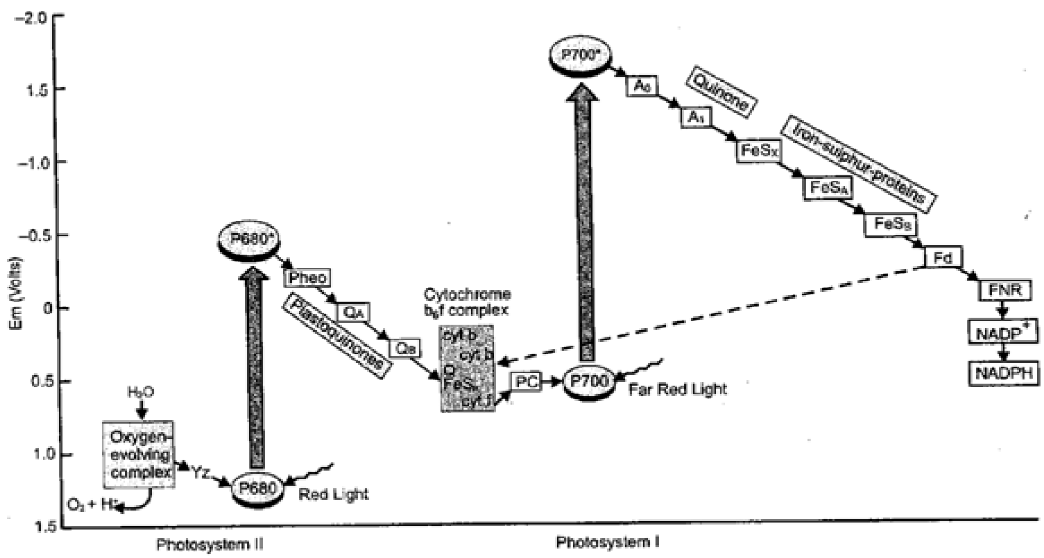


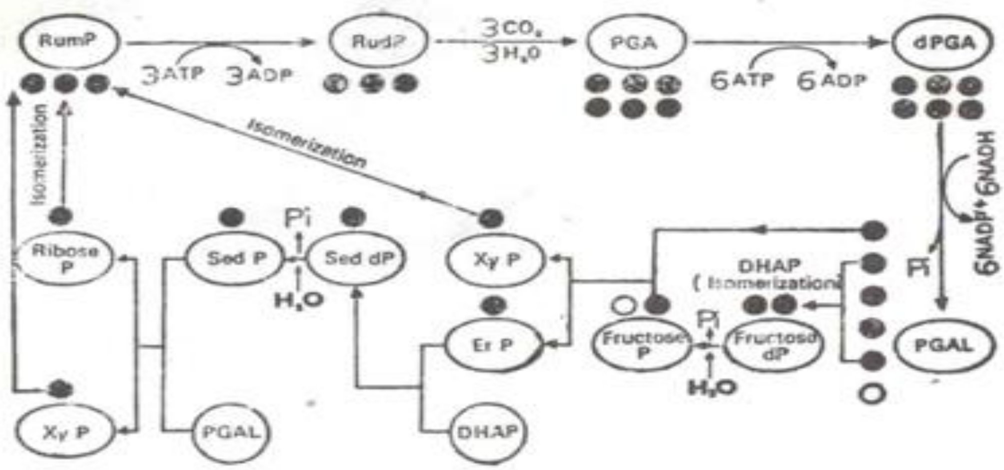
Fig. 7.3 Current concept of the Z-scheme of light phase of photosynthesis. (After Blankenship and Prince, 1985). The cyclic electron transport is indicated by dotted line.

It is however, doubtful whether cyclic process occurs in normal photosynthesis (VAN Niel, 1962), According to Ramirex et al. (1968) it may serve as the source of ATP for biosynthetic processes occurring in chloroplasts that are not on the main photosynthetic path of carbohydrate synthesis but branch off from this path for the synthesis of protein, DNA, RNA, starch, lipids, pigments etc. Part of the ATP requirement of the dark phase of photosynthesis is also met with by this process.

The cyclic electron transport chain was studied by Arnon. It is not inhibited by 3(3), 4-dichlorophenyl 1, 1-dimethylurea: DCMU). This inhibitor, however, inhibits non-cyclic transport of electrons. Cytocrome b_6 is an electron carrier which participates exclusively in cyclic electron transport chain.

7.6 CALVIN CYCLE / DARK REACTION

During the dark reactions of photosynthesis carbon dioxide is reduced to form carbohydrates. The term dark reaction implies that the reaction is not dependent on light. Synthesis of carbohydrates proceeds in the dark. The dark reaction has been worked out mainly by Calvin, Bensn and Bassham. The pathway by which carbon dioxide is fixed into carbohydrates is called the Calvin-Benson cycle or Calvin-Bassham cycle. Carbon dioxide and water are used to generate carbohydrate in the presence of ATP and NADPH. (Fig.7.4).



Outline of the dark reaction.

Outline of the dark reactions

1) 6 Ribulose-1-5-diphosphate + 6 CO_2 + 6 H_2O → 12 3-Phosphoglyceric acid
(RudP) (3 PGA)

2) 12 3-phosphoglyceric acid + 12 ATP → 12 1-3-Diphosphoglyceric acid + 12 ADP
(3 PGA)
12 1-3-Diphosphoglyceric acid + 12 NADPH → 12 Phosphoglyceraldehyde (PGAL) + 12 NADP + 12 Pi

3) 5-Phosphoglyceraldehyde (PGAL) → 5-Dihydroxyacetone phosphate (DHAP)
3 PGAL + 3 Dihydroxyacetone phosphate (DHAP) → 3 Fructose-1-6 diphosphate
3 Fructose-1-6-diphosphate + 3 H_2O → 3 Fructose-6-phosphate + 3 Pi

4) 2 Fructose-6-phosphate + 2 PGAL → 2 Xylulose-5-phosphate + 2 Erythose-4-phosphate

5) 2 Erythrose-4-phospate + 2 DHAP → 2 Sedoheptulose-1-7-diphosphate
2 Sedoheptulose-1-7-diphosphate + 2 H_2O → 2 Sedoheptulose-7-phosphate + 2Pi

6) 2 Sedoheptulose-7-phospate + 2 PGAL → 2 Ribose-5-phosphate + 2 Xylulose-5-Phosphate
2 Ribose-5-phosphate → 2 Ribulose-5-phosphate
4 Xylulose-5-phosphate → 4 Ribulose-5-phosphate (Ribose monophosphate) (RumP)
6 Ribulose-5-phosphate + 6 ATP → 6 Ribulose-1-5-diphosphate + 6 ADP

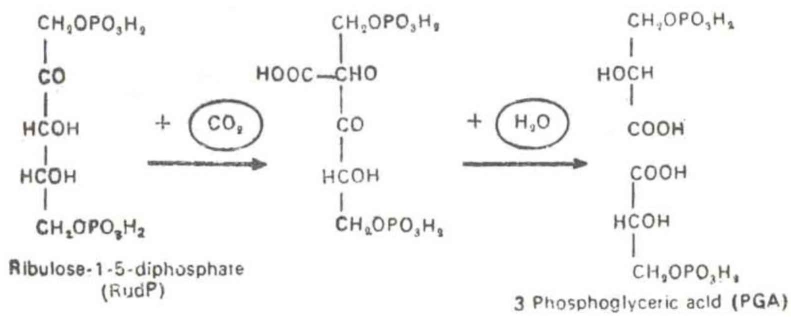
Sum : 6 CO_2 + 18 ATP + 12 NADPH + 12H^+ + 11 H_2O → Fructose-6-phosphate + 18 ADP + 12 $NADP^+$ + 17 H_3PO_4 (Pi)

Fig.7.4 Outline of the dark reactions

1. Production of PGA

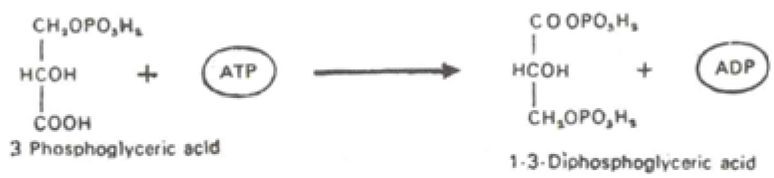
Calvin and his co-workers found that the first product to accumulate during photosynthesis was phosphoglyceric acid (PGA). This arises as follows.

Carbon dioxide is first attached to ribulose-1-5-diphosphate (RudP) a 5-carbon atom compound, to from an intermediate 6-carbon compound. Each molecule of this compound then splits to form two molecules of PGA. Radioactive carbon dioxide ($^{14}CO_2$) was used in the experiment, and this CO_2 contributed one carbon atom of the two PGA molecules formed only one has radioactive carbon. Thus only one free molecule of PGA is formed per molecule of CO_2 entering the cycle. Actually, 6 molecules of RudP and 6 molecules of CO_2 react to produce 12 molecules of PGA.

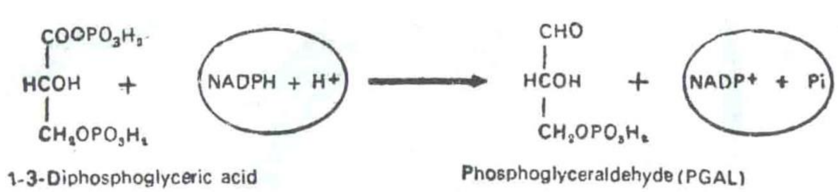


2. Production of PGAL

Phosphoglyceric acid (PGA) is reduced to phosphoglyceraldehyde (PGAL). This Process is the reverse of the oxidation step in glycolysis when PGA is oxidized to PGAL. In all 12 molecules of PGAL are produced from the 6 molecules of RudP. The reaction takes place in two steps. Firstly, PGA is phosphorylated by ATP to 1, 3-diphosphoglyceric acid.

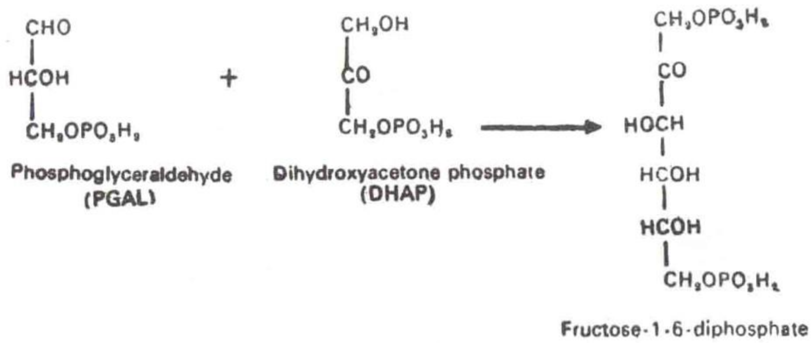


Secondly, 1, 3- diphosphoglyceric acid is reduced by NADPH + H^+ to Phosphoglyceraldehyde (PGAL)



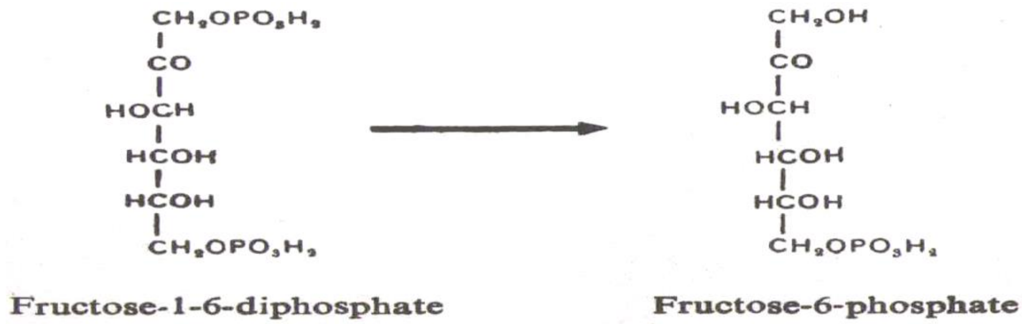
3. Production of Fructose-6- phosphate

PGAL is converted into its isomer dihydroxyactone phosphate (DHAP), as in glycolysis. DHAP condense with PGAL to from fructose-1-6-diphosphate.



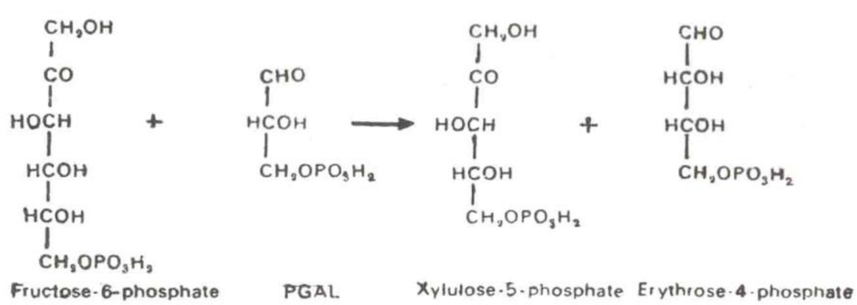
This process is the reverse of the breakdown of fructose-1-6-diphosphate in glycolysis.

One phosphate group is removed from fructose 1-6 diphosphate (dephosphorylation) resulting in the formation of fructose-6-phosphate.



4. Production of Xylulose Phosphate

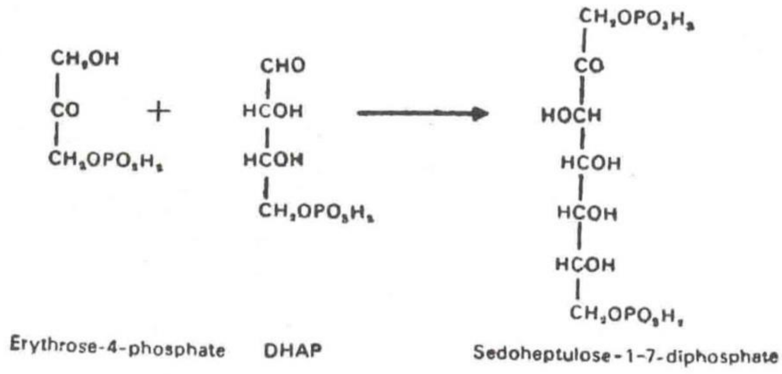
Fructose-6-phosphate reacts with PGAL to yield a pentose (5C), xylulose-5-phosphate, and a tetrose (4C), erythrose-4-phosphate the reaction is catalysed by the enzyme transketolase.



Xylulose-5-phosphate readily isomerizes to *ribulose-5-phosphate*.

5. Formation of Sedoheptulose-1, 7-diphosphate

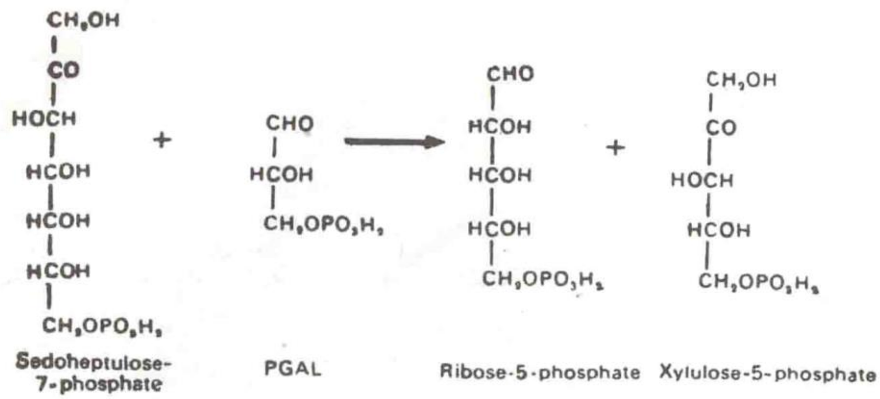
Erythrose-4-phosphate reacts with DHAP to from sedoheptulose-1-7 disposphate, the reaction being catalysed by the enzyme transaldolase.



Sedoheptulose 1-7-diphosphate loses one phosphate (dephosphorylation) and becomes sedoheptulose-7-diphosphate.

6. Formation of Ribose-5-phosphate

Sedoheptulose-7-phosphate reacts with another molecule of PGAL to from ribose-5-phosphate and xyluose-5-phosphate. Both these products readily isomerizes to ribulose-5-phosphate or ribulose monophosphate (RumP)



7.7 C4 PATHWAYS

Most of the C_4 plants are monocots. There are also about 300 species of C_4 plants in dicots. About 900 species belonging to 19 families are C_4 plants. The primary objective of the Hatch Slack cycle is to trap atmospheric CO_2 in the maximum amount and to transport it into the bundle sheath cells so that the rate of Calvin cycle is enhanced.

Till 1965 the mechanism of the photosynthetic CO_2 fixation was believed to occur only by means of what is popularly known as Calvin cycle. In 1965 H.P. Kortschak, C.E. Hart can G.O. Burr working with $C^{14}O_2$ on sugar cane leaves found highly efficient photosynthesis and C_4 dicarboxylic acid, malate and aspartate to be the major labeled products (80% of radio activity) in very short periods of photosynthesis. Working on grasses this observation was confirmed by

M.D. Hatch and C.R. Slack of David North Plant Research Centre, Queensland, Australia in 1967. The Hatch Slack pathway, as this alternative CO_2 fixation is called, has been found to occur in tropical and subtropical grasses and some dicotyledons. Some of the important C_4 plants are sugarcane, maize, sorghum etc. It is interesting to note that even within a single genus a sub-tropical species *Atriplex rosea* exhibits Hatch Slack pathway whereas the temperate species *Atriplex hastata* has only the Calvin cycle.

There are 4 distinct stages in the C_4 cycle:

1. CO_2 fixation in the mesophyll by phosphoenol pyruvate to form C_4 acids: malic and aspartic acids.
2. The transfer of C_4 acids into the bundle sheath through plasmodesmata.
3. Decarboxylation of the C_4 acids in the bundle sheath.
4. The diffusion of pyruvate or alanine back into the mesophyll for the regeneration of CO_2 acceptor pyruvate.

In Hatch Slack cycle the first step occurs in the cytoplasm of the mesophyll where PEP Carboxylase (PEPcase) brings about the following reaction in the presence of water.

$$CO_2 + H_2 \longrightarrow HCO_3^- + H^+$$

$$PEP + HCO_3^- \xrightarrow[\text{carboxylase}]{\text{PEP}} \text{Oxaloacetate}$$

The oxaloacetate then moves into the chloroplast where it is reduced to malate by the enzyme malic acid dehydrogenase which is present inside the chloroplast.

$$\text{Oxaloacetate} + NADPH + H^+ \xrightarrow[\text{dehydrogenase}]{\text{malate}} \text{Malate} + NADP^+$$

The oxaloacatate is also transaminated into aspartate. The malate diffuses into the cells of bundle sheath through plasmodesmata (fig. 7.5).The malate is decarboxylated within the cells of the bundle sheath by $NADP^+$ dependent malic enzyme to produce CO_2 and pyruvate. While CO_2 is taken up by RuBP to accelerate the calvin cycle the pyruvate diffuses back to the mesophyll cell. The pyruvic acid reacts with ATP and an inorganic phosphate in the presence of an enzyme present in the chloroplast known as pyruvate phosphate dikinase to produce phosphoenolpyruvic acid, AMP and pyrophosphate.

$$\text{Pyruvic acid} + ATP + Pi \xrightarrow[\text{dikinase}]{\text{pyruvate phosphate}} \text{Phosphoenol pyruvic acid} + AMP + P\text{-}Pi$$

The number of ATP molecules required to synthesis one hexose is, therefore, much more than that of the Calvin cycle. The enzyme pyruvate orthophosphate dikinase brings about the conversation of pyruvic acid into phosphoenol pyruvic acid by breaking up of two energy rich bonds of ATP. The conversion of AMP back into ATP requires expenditure of two ATP molecules. While in Calvin cycle the requirement is 18 ATP in C_4 plants, 12 extra ATP are required because two additional ATP per CO_2 are essential for regenerating ATP from AMP. Phosphophenolpyruvate carboxylase, pyruvate phosphate dikinase and the $NADP^+$ specific malate dehydrogenase are present in the chloroplasts of the mesophyll cells, whereas RUBP carboxylase NADP specific malic enzyme, and the remaining Calvin cycle enzymes have been found to be present in the chloroplasts of a layer of paranchymatous cells which form a sheath around the vascular bundle. Plasmodesmata have been observed to connect adjacent cells of the bundle sheath and mesophyll layer in maize and sugarcane.

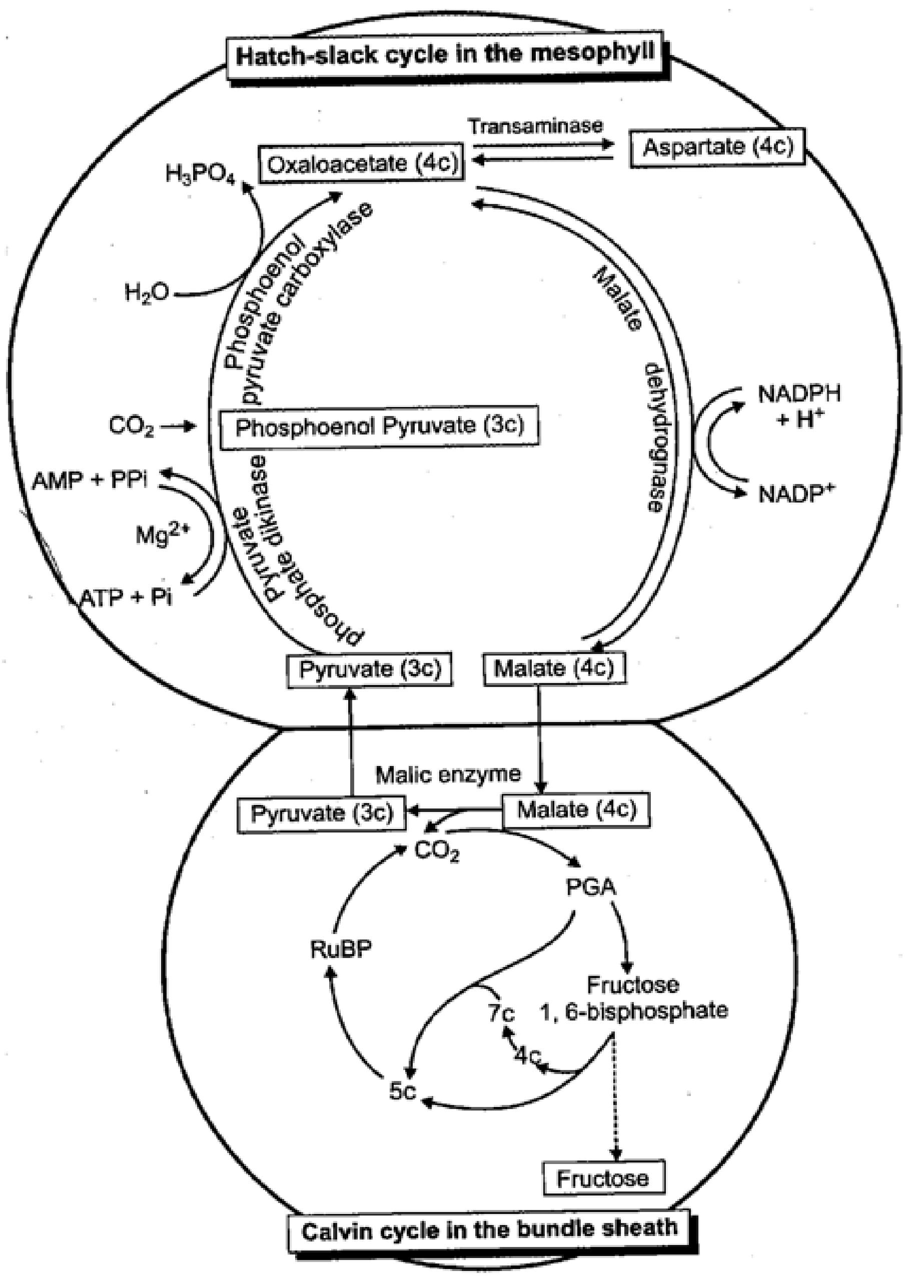


Fig.7.5 Hatch-Slack cycle and Calvin cycle as they occur within the mesophyll and bundle sheath of the C_4 plants

7.8 CAM PLANTS

The members of the family Crassulaceae have a special type of metabolism called Crassulacean acid metabolism (CAM) which is also exhibited by member of other families. CAM plant are succulents with thick fleshy leaves, or, when leaves are absent, a swollen photosynthetic stem. CAM plant can synthesize large amounts of malic and isocitric acids at night. Photosynthesis occurs during the day and these acids disappear. The stomata of the leaves remain closed during the day and open only at night. This is an adaptation to conserve water, since succulents exhibiting CAM are found in dry habitats. During the night Co_2 is taken into the leaves through the open stomata. Because photosynthesis is limited by the storage pool of organic acid and carbohydrate, CAM plants are generally slow growing. (Fig.7.6).

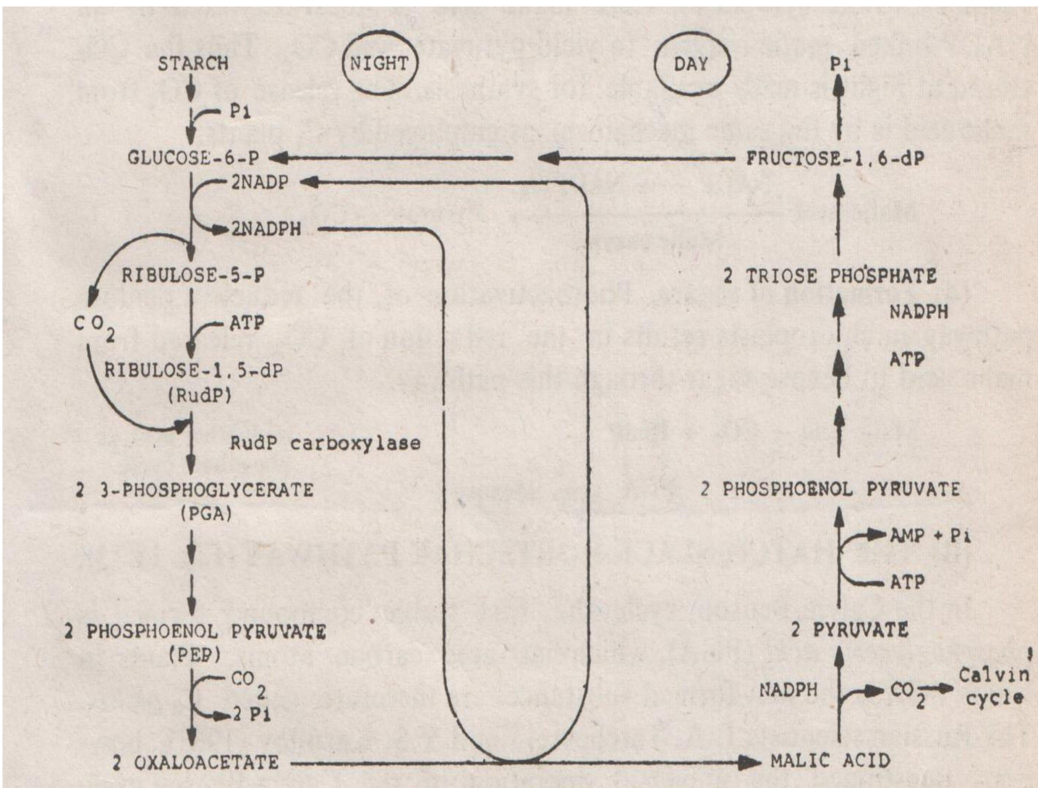


Fig.7.6 Crassulaecean acid metabolism

The CAM mechanism shows various modifications. Well watered *Agave americana* shows some normal daytime photosynthesis along with some CO_2 fixation at night. In watered *Agave deserti*, however, dark carboxylation stops and is replaced by normal C_3 daytime photosynthesis.

7.8.1 Reactions of CAM

(1) **Formation of oxaloacetate**. The requirements for formation of oxaloacetate are CO_2 and phosphoenol pyruvic acid (PEP). PEP is formed from stored carbohydrate in leaves, particularly starch. In CAM species the stomata remain open at night and CO_2 entering the leaves are fixed by PEP to form oxaloacetate.

$$CO_2 + PEP \longrightarrow \text{Oxaloacetate} + Pi$$

(2) **Formation of Malic acid-** Oxaloacetate is reduced by malic dehydrogenase to malic acid, which accumulates in the vacuoles of leaf cells. During this step $NADPH_2$ formed in the pentose phosphate pathway is utilized, and the NADP formed enters the pentose phosphate pathway.

$$\text{Oxaloacetate} \xrightarrow{NADPH_2 \rightarrow NADP} \text{Malic acid}$$

(3) **Release of CO_2 from malic acid.** – During the day ATP and NADPH are abundantly available from the photosynthesis reactions. The stomata of the leaves are closed and malate is transported back out of the vacuoles to the cytoplasm. Here malic acid is decarboxylated by an NADP-linked malic enzyme to yield pyruvate and CO_2. Thus the CO_2 stored at night is made available for synthesis. The release of CO_2 from malic acid is by the same mechanism as employed by C_4 plants.

$$\text{Malic acid} \xrightarrow[\text{Malic enzyme}]{NADP \rightarrow NADPH_2} \text{Pyruvate} + CO_2$$

(4) **Formation of sugar** – Photoactivation of the reductive pentose pathway in chloroplasts results in the reduction of CO_2 released from malic acid to hexose sugar through this pathway.

$$\text{Malic acid} \rightarrow CO_2 \rightarrow \text{RudP} \underset{\text{PGA} \rightarrow \text{Hexose}}{\uparrow\downarrow} \qquad \text{Reductive pentose phosphate cycle}$$

7.9 PHOTORESPIRATION

Although C_3 plants respire in the dark, the rate of oxygen utilization increases markedly when the plants are illuminated. Photorespiration is a light driven efflux of CO_2 which proceeds alongside with net CO_2 influx during photosynthesis. Photorespiration may attain 50% of the net rate of photosynthesis. Photorespiration results in CO_2 evolution in light. This has the net effect of decreasing photosynthesis which takes up CO_2 in light. It is therefore a wasteful process which prevents plants from achieving a maximum yield in photosynthesis. In crop species the yield would be greater if photorespiration did not occur. The substrate for photorespiration is glycollate. Breeding of plants with lower photorespiration rates, or inhibiting glycollate synthesis, would be means of increasing crop yields.

Photorespiration is exhibited by crop plants like wheat, rice, other cereals, many legumes and sugar beets, while crops like corn, sorghum and sugarcane do not have photorespiration. (Fig. 7.7).

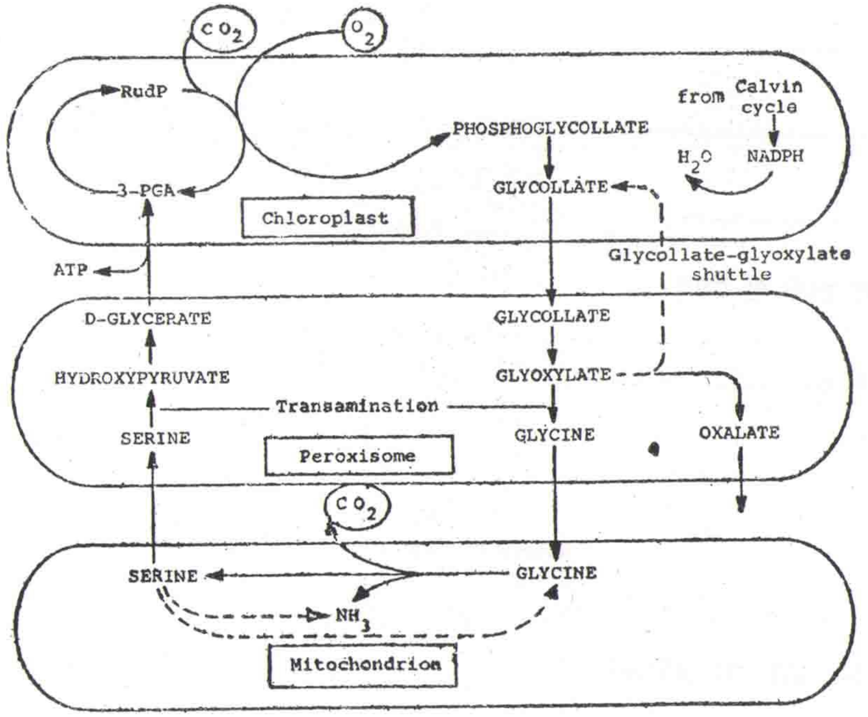


Fig.7.7 Some pathways in glycollate metabolism

The CO_2 compensation point is the CO_2 concentration at a given constant light intensity at which there is a balance between photosynthetic assimilation and respiration. The enzymes of the photo respiratory pathways are present in both C_3 and C_4 plants. The carbondioxide compensation point for common C_3 crop plants is about 40-60 ppm at 25^O C, while that for C_4 plants is often less than 10 ppm. The CO_2 generated in C_4 plants during photorespiration is trapped and re-cycled internally by cytoplasmic PEP carboxylase of mesophyll cells. Thus CO_2 efflux is prevented.

Glycollic acid is a 2-carbon compound which is formed in large quantities in the chloroplasts of C_3 plants, from where it moves out into the cytosol.

7.10 RESPIRATION

Respiration starts with glucose (usually). In aerobic and anaerobic respiration initial reactions are common as a result of which pyruvic acid is formed by breakdown of glucose. The process is called Glycolysis or EMP Pathway (Embden-Meyerhof-Parnas Pathway). This process does not require O_2 although this can take place in the presence of oxygen. After this stage, the fate of pyruvic acid is different depending upon the presence or absence of oxygen.

If oxygen is present there is complete oxidation of pyruvic acid into H_2O and CO_2 and chemical reactions through which this occurs is called Tri-Carboxylic Acid cycle (TCA Cycle) or Kreb's Cycle. This cycle occurs in mitochondria. If oxygen is absent, pyruvic acid forms ethyl alcohol (C_2H_5OH) and CO_2 without the help of any cell organelle. This process is called anaerobic respiration.

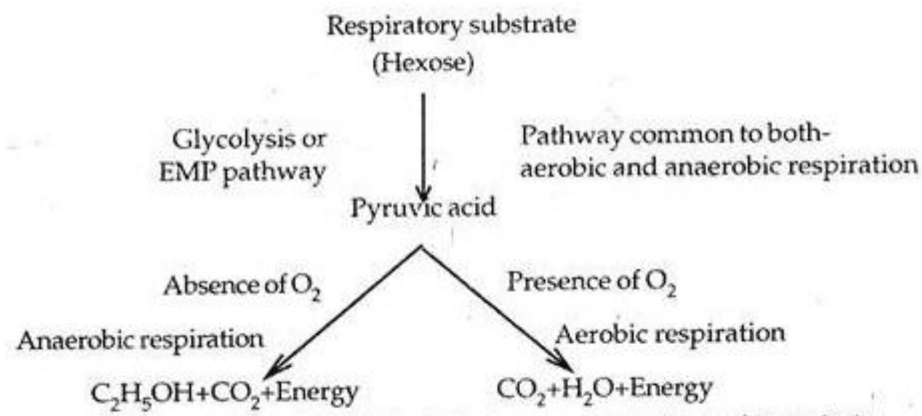


Fig.7.8 Schematic representation of interrelationship between aerobic and anaerobic respiration

7.11 AEROBIC RESPIRATION

Aerobic respiration is an enzymatically controlled release of energy in a stepwise catabolic process of complete oxidation of organic food into carbon dioxide and water with oxygen acting as terminal oxidant. The common mechanism of aerobic respiration is also called common pathway because its first step, called glycolysis, is common to both aerobic and anaerobic modes of respiration. The common aerobic respiration consists of three steps—glycolysis, Krebs cycle and terminal oxidation.

Glycolysis

It is also called EMP pathway because it was discovered by three German scientists Embden, Meyerhof and Parnas. Glycolysis is the process of breakdown of glucose or similar hexose sugar to molecules of pyruvic acid through a series of enzyme mediated reactions releasing some energy (as ATP) and reducing power (as $NADH_2$) (Fig 7.9). It occurs in the cytoplasm. It takes place in the following sub steps.

a. Phosphorylation:

Glucose is phosphorylated to glucose-6-phosphate by ATP in the presence of enzyme hexokinase (Meyerhof, 1927) or glucokinase (e.g., liver) and Mg^{2+}.

$$\text{Glucose} + \text{ATP} \xrightarrow[Mg^{2+}]{\text{hexokinase}} \text{Glucose-6-phosphate} + \text{ADP}$$

b. Isomerization:

Glucose-6-phosphate is changed to its isomer fructose-6-phosphate with the help of enzyme phosphohexose isomerase.

$$\text{Glucose 6-phosphate} \underset{\text{Isomerase, } Mg^{2+}}{\overset{\text{Phosphohexose}}{\rightleftharpoons}} \text{Fructose-6-phosphate}$$

Fructose-6-phosphate can also be produced directly by phosphorylation of fructose with the help of enzyme fructokinase.

$$\text{Fructose} + \text{ATP} \xrightarrow[Mg^{2+}]{\text{Fructokinase}} \text{Fructose-6-phosphate} + \text{ADP}$$

c. Phosphorylation:

Fructose-6-phosphate is further phosphorylated by means of ATP in presence of enzyme phosphofructo-kinase and Mg^{2+}. The product is Fructose-1, 6 diphosphate.

$$\text{Fructose-6-phosphate} + \text{ATP} \xrightarrow[\text{kinase} + Mg^{2+}]{\text{Phosphofructo-}} \text{Fructose-1, 6-diphosphate} + \text{ADP}$$

d. Splitting:

Fructose-1, 6-diphosphate splits up enzymatically to form one molecule each of 3- carbon compounds, glyceraldehyde 3-phosphate (= GAP or 3-phosphoglyceraldehyde = PGAL) and dihydroxy acetone 3-phosphate (DIHAP). The latter is further changed to glyceraldehyde 3-phosphate by enzyme triose phosphate isomerase (= phosphotriose isomerase).

$$\text{Fructose-1, 6-diphosphate} \overset{\text{Aldolase}}{\rightleftharpoons} \text{Glyceraldehyde 3-phosphate (GAP) or Phosphyglyceraldehyde (=PGAL)} + \text{Dihydroxyacetone 3-phosphate}$$

$$\text{Dihydroxy acetone 3-phosphate} \underset{\text{isomerase}}{\overset{\text{Triose phosphate}}{\rightleftharpoons}} \text{Glyceraldehyde 3-phosphate}$$

e. Dehydrogenation and Phosphorylation:

In the presence of enzyme glyceraldehyde phosphate dehydrogenase, glyceraldehyde 3-phosphate loses hydrogen to NAD to form $NADH_2$ and accepts inorganic phosphate to form 1, 3-diphosphoglyceric acid.

$$\text{Glyceraldehyde 3-phosphate} + H_3PO_4 + NAD^+ \underset{\text{Dehydrogenase}}{\overset{\text{Glyceraldehyde Phosphate}}{\rightleftharpoons}} \text{1,3-diphosphoglyceric acid} + NADH + H^+$$

f. Formation of ATP:

One of the two phosphates of diphosphoglyeerie acid in linked by high energy bond. It can synthesise ATP and form 3-phosphoglyceric acid. The enzyme is phosphoglyceryl inase. The direct synthesis of ATP from metabolites is called substrate level phosphorylation.

$$\text{1, 3-diphosphoglyceric acid + ADP} \overset{\text{Phosphoglyceryl}}{\rightleftharpoons} \text{3- phosphoglyceric acid + ATP}$$

g. Isomerization:

3-phosphoglyceric acid is changed to its isomer 2-phosphoglyceric acid by zyme phosphoglyceromutase.

$$\text{3-diphosphoglyceric acid} \overset{\text{phosphoglyceromutase}}{\rightleftharpoons} \text{2-phosphoglyceric acid}$$

h. Dehydration:

Through the agency of enzyme enolase, 2-phosphoglyceric acid is converted to phosphoenol pyruvate (PEP). A molecule of water is removed in the process. Mg^{2+} is required.

$$\text{2-Phosphoglyceric acid} \underset{Mg^{2+}}{\overset{\text{Enolase}}{\rightleftharpoons}} \underset{\text{(PEP)}}{\text{Phosphoenol Pyruvate}} + H_2O$$

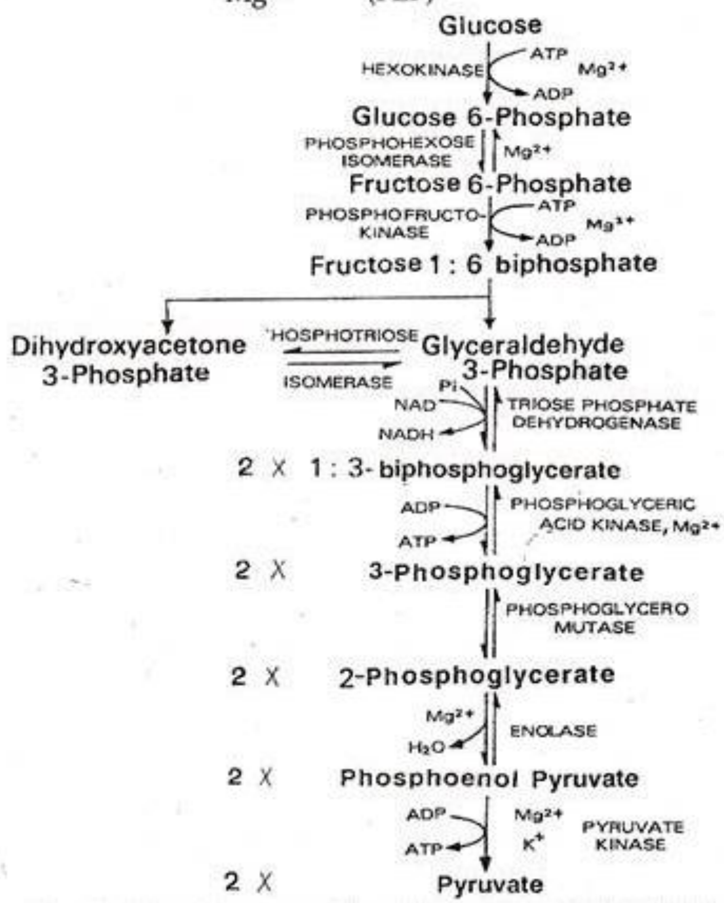


Fig. 7.9 Schematic representation of glycolysis or EMP pathway

i. Formation of ATP:

During formation of phosphoenol pyruvate the phosphate radical picks up energy. It helps in the production of ATP by substrate level phosphorylation. The enzyme is pyruvic kinase. It produces pyruvate from phosphoenol pyruvate.

$$\text{Phosphoenol Pyruvate} + \text{ADP} \underset{Mg^{2+}, K^{+}}{\overset{\text{Pyruvic Kinase}}{\rightleftharpoons}} \text{Pyruvate (Pyruvic acid)} + \text{ATP}$$

Net products of glycolysis:

In glycolysis two molecules of ATP are consumed during double phosphorylation of glucose to form fructose-1, 6 diphosphate. In return four molecules of ATP are produced by substrate level phosphorylation (conversion of 1, 3 diphosphoglyceric acid to 3-phosphoglyceric acid and phosphenol pyruvate to pyruvate). Two molecules of $NADH_2$ are formed at the time of oxidation of glyceraldehyde 3-phosphate to 1, 3-diphosphoglyceric acid. The net reaction is as follows:

$$Glucose+2NAD^{+}+2ADP+2H_3PO_4+2H_3PO_4 \rightarrow 2\ Pyruvate+2NADH+2H^{+}+2ATP$$

Krebs Cycle

The cycle was discovered by Hans Krebs (1937, 1940, Nobel Prize 1953). It occurs inside mito-chondria. The cycle is also named as citric acid cycle or tricarboxylic acid (TCA) cycle after the initial product. Krebs cycle is stepwise oxidative and cyclic degradation of activated acetate derived from pyruvate (Fig. 7.10).

Oxidation of Pyruvate to Acetyl-CoA:

Pyruvate enters mitochondria. It is decarboxylated oxidatively to produce CO_2 and NADH. The product combines with sulphur containing coenzyme A to form acetyl CoA or activated acetate. The reaction occurs in the presence of an enzyme complex pyruvate dehydrogenase (made up of a decarboxylase, lipoic acid, TPP, transacetylase and Mg^{2+}).

$$\text{Pyruvate} + NAD^{+} + \text{CoA} \xrightarrow[\text{Dehyrogenase}]{\text{Pyruvate}} \text{Acetyl CoA} + NADH + H^{+} + CO_2$$

Acetyl CoA functions as substrate entrant for Krebs cycle. The acceptor molecule of Krebs cycle is a 4-carbon compound oxaloacetate. Kerbs cycle involves two decarboxylations and four dehydroge- nations. The various components of Krebs cycle are as follows.

a. Condensation:

Acetyl CoA (2-carbon compound) combines with oxalo-acetate (4-carbon compound) in the presence of condensing enzyme citrate synthetase to form a tricarboxylic 6-carbon compound called citric acid. It is the first product of Krebs cycle. CoA is liberated.

$$\text{Acetyl CoA} + \text{Oxaloacetate} + H_2O \xrightarrow[\text{Synthetase}]{\text{Citrate}} \text{Citrate} + \text{CoA}$$

b. Dehydration:

Citrate undergoes reorganisation in the presence of aconitase forming cis aconitate releasing water.

$$\text{Citrate} \xrightarrow[\text{Synthetase}]{\text{Aconitase}} \text{cis-aconitate} + H_2O$$

c. Hydration:

Cis-aconitate is converted into isocitrate with the addition of water in the presence of iron containing enzyme aconitase.

$$\text{Cis–aconitate} + H_2O \xrightarrow{\text{Aconitase}} \text{Isocitrate}$$

d. Dehydrogenation:

Isocitrate is dehydrogenated to oxalosuccinate in the presence of enzyme isocitrate dehydrogenases and Mn^{2+}. $NADH_2$ ($NADPH_2$) is produced.

$$\text{Isocitrate} + NAD^+ \xrightarrow[\text{dehydrogenase, } Mn^{2+}]{\text{Isocitrate}} \text{Oxalosuccinate} + NADH + H^+$$

e. Decarboxylation:

Oxalosuccinate is decarboxylated to form a-ketoglutarate through enzyme decarboxylase. Carbon dioxide is released.

$$\text{Oxalosuccinate} \xrightarrow{\text{Decarboxylase}} \alpha\text{-Ketoglutarate} + CO_2$$

f. Dehydrogenation and Decarboxylation:

α-Ketoglutarate is both dehydrogenated (with the help of NAD^+) and decarboxylated by an enzyme complex a-ketoglutarate dehydrogenase. The enzyme complex contains TPP and lipoic acid. The product combines with CoA to form succinyl CoA.

$$\text{a-kethylutoxate} + \text{CoA} + NAD^+ \xrightarrow[\text{dehydrogenase}]{\alpha\text{-ketoglutarate}} \text{Succinyl CoA} + NADH + H^+ + CO_2\text{-}$$
$$(\textit{TPP. Lipoic acid } Mg^{2+})$$

g. Formation of ATP/GTP:

Succinyl CoA is acted upon by enzyme succinyl thiokinase to form succinate. The reaction releases sufficient energy to form ATP (in plants) or GTP (in animals).

$$\text{Succinyl CoA} + \text{GDP/ADP} + H_3PO_4 \xrightarrow[\text{Thiokinase}]{\text{Succinyl}} \text{Succinate} + \text{CoA} + \text{GTP/ATP}$$

h. Dehydrogenation:

Succinate undergoes dehydrogenation to form fumarate with the help of a dehydrogenase. $FADH_2$ (reduced flavin adenine dinucleotide) is produced.

Succinate + FAD Succinate, → Dehydrogenase, Fumarate + $FADH_2$

i. Hydration:

A molecule of water gets added to fumarate to form malate. The enzyme is called fumarase.

$$\text{Fumarate} + H_2O \xrightleftharpoons{\text{Fumarase}} \text{Malate}$$

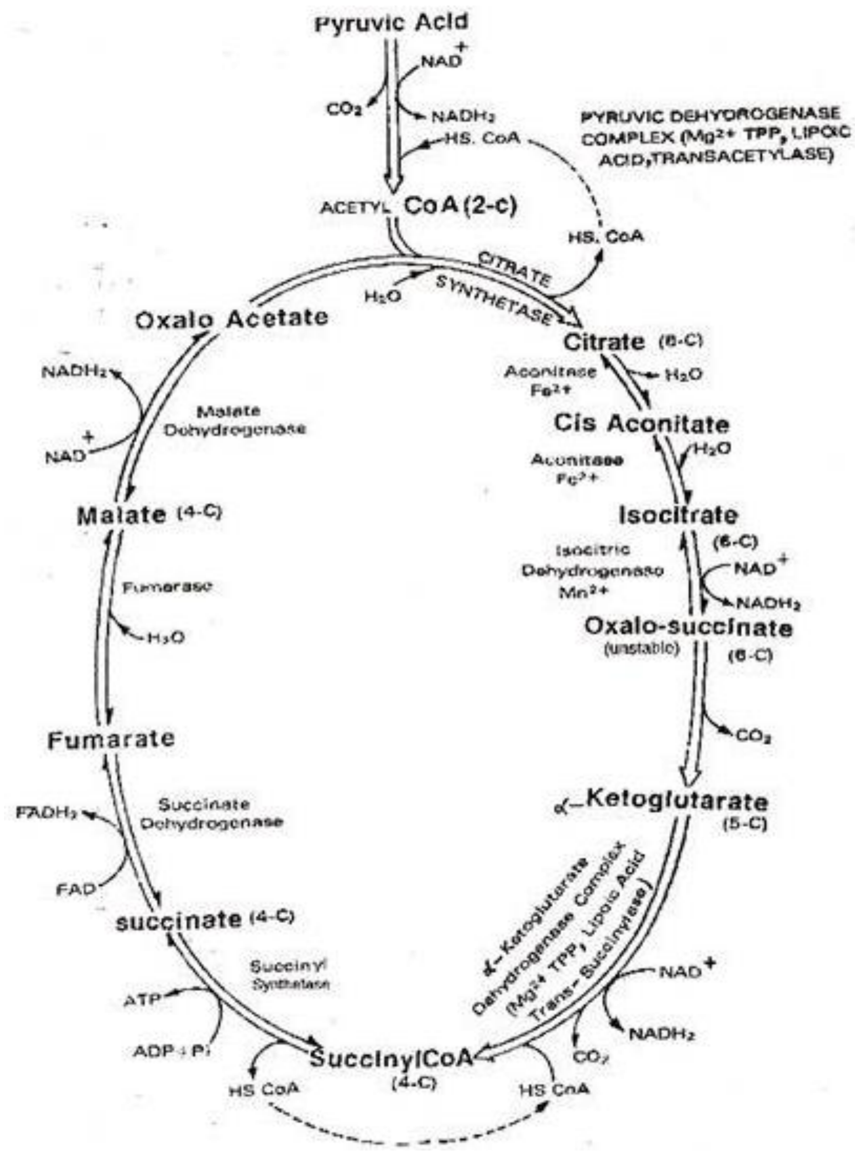


Fig.7.10 Schematic representation of Krebs cycle or TCA cycle

j. Dehyrogenation:

Malate is dehydrogenated or oxidised through the agency of malate dehydrogenase to produce oxaloacetate. Hydrogen is accepted by NADP$^+$ NAD$^+$

$$\text{Malate} + \text{NAD (P)}^+ \underset{\text{Dehydrogenase}}{\overset{\text{Malate}}{\rightleftharpoons}} \text{Oxaloacetate} + \text{NAD (P)H} + \text{H}^+$$

Oxaloacetate picks up another molecule of activated acetate to repeat the cycle.

A molecule of glucose yields two molecules of $NADH_2$, 2ATP and two pyruvate while undergoing glycolysis. The two molecules of pyruvate are completely degraded in Krebs cycle to form two molecules of ATP, $8NADH_2$, and $2FADH_2$.

Glucose + 4ADP + $4H_3PO_4$+10NAD$^+$ + 2FAD -> $6CO_2$ + 4ATP + 10NADH + 10H$^+$ +$2FADH_2$

Terminal Oxidation

It is the name of oxidation found in aerobic respiration that occurs towards the end of catabolic process and involves the passage of both electrons and protons of reduced coenzymes to oxygen.

$$FADH_2 \rightleftharpoons FAD + 2H^+ + 2e^-$$
$$\frac{1}{2}O_2 + 2H^+ + 2e^- \longrightarrow H_2O$$

Terminal oxidation consists of two processes-electron transport and oxidative phosphorylation.

Electron ransport Chain:

Inner mitochondrial membrane contains groups of electron and proton transporting enzymes. In each group the enzymes are arranged in a specific series called electron transport chain (ETC) or mitochondrial rTespiratory chain or electron transport system (ETS). (Fig.7.11)

An electron transport chain or system is a series of coenzymes and cytochromes that take part in the passage of electrons from a chemical to its ultimate acceptor. The passage of electrons from one enzyme or cytochrome to the next is a downhill journey with a loss of energy at each step. At each step the electron carriers include flavins, iron sulphur complexes, quinones and cytochromes.

Most of them are prosthetic groups of proteins. Quinones are highly mobile electron carriers. Four enzymes are involved in electron transport—(i) NADH-Q reductase or NADH-dehydrogenase (ii) Succinate Q-reductase complex (iii) QH_2-cytochrome c reductase complex (iv) Cytochrome c oxidase complex. NADH-Q reductase (or NADH- dehydrogenase) has two prosthetic groups, flavin mononucleotide (FMN) and iron sulphur (Fe-S) complexes. Both electrons and protons pass from $NADH_2$ to FMN. The latter is reduced.

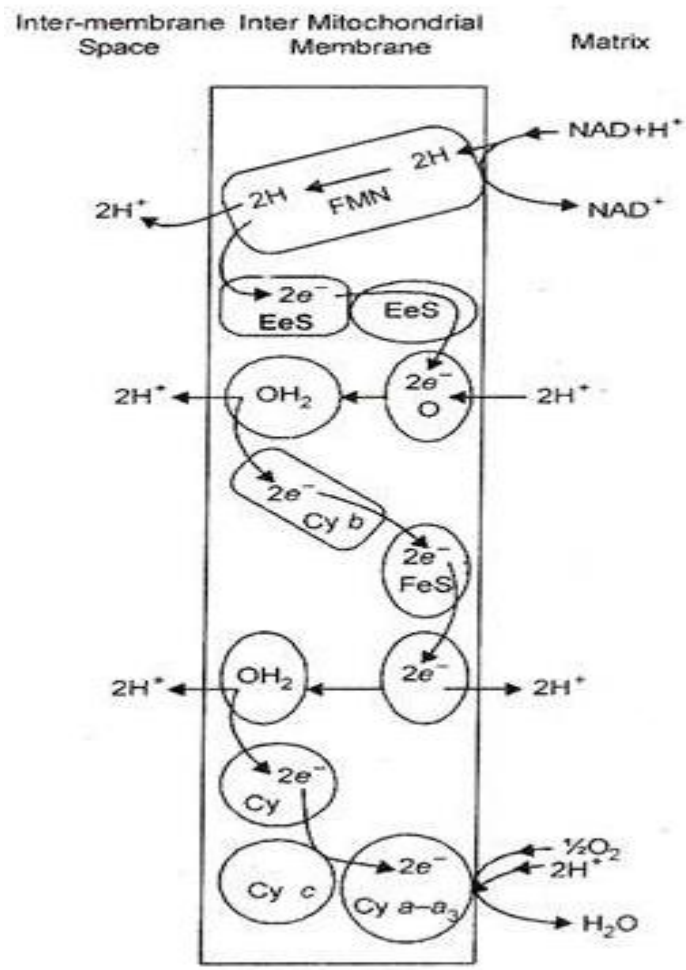


Fig.7.11 Electron Transport System (ETS)

$NADH + H^+ + FMN$——> $FMNH_2 + NAD^+$

Electron now moves to the FeS complex and from there to a quinone. The common quinone is co-enzyme Q, also called ubiquinone (UQ).

$FMNH_2 + 2Fe^{3+} S$——>$FMN + 2Fe^{2+} S + 2H^+$

$2Fe^{2+} S + Q + 2H^+$——>$2Fe^{3+} S + QH_2$

$FADH_2$ produced during reduction of succinate also hands over its electrons and protons to co-enzyme Q through FeS complex. The enzyme is succinate-Q reductase complex.

$FADH_2 + 2Fe^{3+} S$——> $2Fe^{2+} S + 2H^+ + FAD$

$2Fe^{2+} S + Q + 2H^+$——> $2Fe^{3+} S + QH_2$

QH_2-cytochrome c reductase complex has three components—cytochrome b, FeS complex and cytochrome c_1. Coenzyme Q may also be involved between FeS complex and cytochrome c_1.

$QH_2 + 2Fe^3 + $ cyt.b ——> Q + $2H^+ + 2Fe^2$+cyt.b

$2Fe^2 +$ cyt.b + $2Fe^{3+}$ S ——> $2Fe^3 +$ cyt.b + $2Fe^2 +$ S

$2Fe^{2+}$ S + Q + $2H^+$——> $2Fe^3 +$ S + QH_2 (?)

$QH_2 + 2Fe^{3+}$ cyt.c_1 ——> Q + $2H^+ + 2Fe^{2+}$cyt.c_1

Cytochrome c_1 hands over its electron to cytochrome c. Like co-enzyme Q, cytochrome c is also mobile carrier of electrons.

$2Fe^{2+}$ cyt.c_1 + $2Fe^{3+}$ cyt.c ——> $2Fe^3$ cyt.c_1 + $2Fe^{2+}$ cyt.c

Cytochrome c oxidase complex comprises cytochrome a and cytochrome a_3. Cytochrome a_3 also possesses copper. The latter helps in transfer of electron to oxygen.

$2Fe^{2+}$ cyt.c + $2Fe^{3+}$ cyt.a ——> $2Fe^{3+}$ cyt.c + $2Fe^{2+}$ Cyt.a

$2Fe^{2+}$ cyt.a + $2Fe^{3+}$ cyt.a_3 Cu^{2+} ——> $2Fe^{3+}$ cyt.a + $2Fe^{2+}$ cyt.a_3 Cu^{2+}

$2Fe^2$ cyt.a_3 Cu^{2+} ——> $2Fe^3$ cyt.c_3 Cu^{1+}

$2Fe^3$ cyt.a_3 Cu^{1+} + [O] ——> $2Fe^{3+}$ cyt.a_3 Cu^{2+}+ [O]

Oxygen is the ultimate acceptor of electrons. It becomes reactive and combines with protons to form metabolic water.

$2H^+$ + O"——— > $2H_2O$

Energy released during passage of electrons from one carrier to the next is made available to specific transmembrane complexes, which pump protons ((H^+) from the matrix side of the inner mitochondrial membrane to the outer chamber. There are three such sites corresponding to three enzymes present in the electron transport chain (NADH-Q reductase, QH_2-cytcxhrome c reductase and cytochrome c-oxidase).

This increases proton concentration in the outer chamber or outer surface of the inner mitochondrial membrane. The difference in the proton concentration on the outer and inner sides of the inner mitochondrial membrane is known as proton gradient. (Fig 7.12)

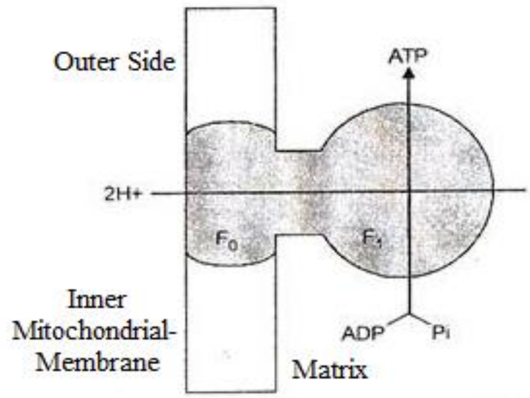


Fig.7.12 Diagrammatic representation of ATP synthesis in mitochondria

Oxidative Phosphorylation:

Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes ($NADH_2$, $FADH_2$) produced in respiration. The enzyme required for this synthesis is called ATP synthetase.

It is located in F_1 or head piece of F_0-F_1 or elementary particles present in the inner mitochondrial membrane. ATP-synthetase becomes active in ATP formation only where there is a proton gradient having higher concentration of H^+ or protons on the F_0 side as compared to F_1 side (chemiosmotic hypothesis of Peter Mitchel, 1961).

Increased proton concentration is produced in the outer chamber or outer surface of inner mitochondrial membrane by the pushing of protons with the help of energy liberated, by passage of electrons from one carrier to another.

Transport of the electrons from $NADH_2$ over ETC helps in pushing three pairs of protons to the outer chamber while two pairs of protons are sent outwardly during electron flow from $FADH_2$ (as the latter donates its electrons further down to the ETC).

Higher proton concentration in the outer chamber causes the protons to pass inwardly into matrix or inner chamber through the inner membrane. The latter possesses special proton channels in the region of F_Q (base) of the F_0—F_1 particles.

The flow of protons through the F_0 channel induces F, particles to function as ATP-synthetase. The energy of the proton gradient is used in attaching a phosphate radicle to ADP by high energy bond. This produces ATP. Oxidation of one molecule of $NADH_2$ produces 3 ATP molecules while a similar oxidation of $FADH_2$ forms 2 ATP molecules.

2 ATP molecules are produced during glycolysis and 2 ATP (GTP) molecules during double Krebs cycle. Glycolysis also forms $2NADH_2$. Its reducing power is transferred to mitochondria

for ATP synthesis. For this a shuttle system operates at the inner mitochondrion membrane. (i) $NADH_2$ —> NAD -> $NADH_2$. (ii) $NADH_2$ -> FAD -> $FADH_2$.

The former operates in liver, heart and kidney cells. No energy is spent. The second method occurs in muscle and nerve cells. It lowers the energy level of 2NADH2 by 2ATP molecules. A total of 10 $NADH_2$ and 2$FADH_2$ molecules are formed in aerobic respiration.

They help in formation of 34 ATP molecules. The net gain from complete oxidation of a molecule of glucose in muscle and nerve cells is 36 ATP molecules (10 $NADH_2$ = 30 ATP, 2 $FADH_2$ = 4 ATP, four formed by substrate level phosphorylation in glycolysis and Krebs cycle and two consumed in transport of the$NADH_2$ molecules into mitochondria). (Fig 7.13)

In procaryotes, heart, liver, and kidneys, 38 ATP molecules are produced per glucose molecules oxidised. Passage of ATP molecules from inside of mitochondria to cytoplasm is through facilitated diffusion.

Since, one ATP molecule stores 8.9 kcal/mole (7 kcal/mole according to early estimates) the total energy trapped per gm mole of glucose is 338.2 kcal (266 kcal) or an efficiency of 49.3% (38.8% according to older estimates). The rest of the energy is lost as heat.

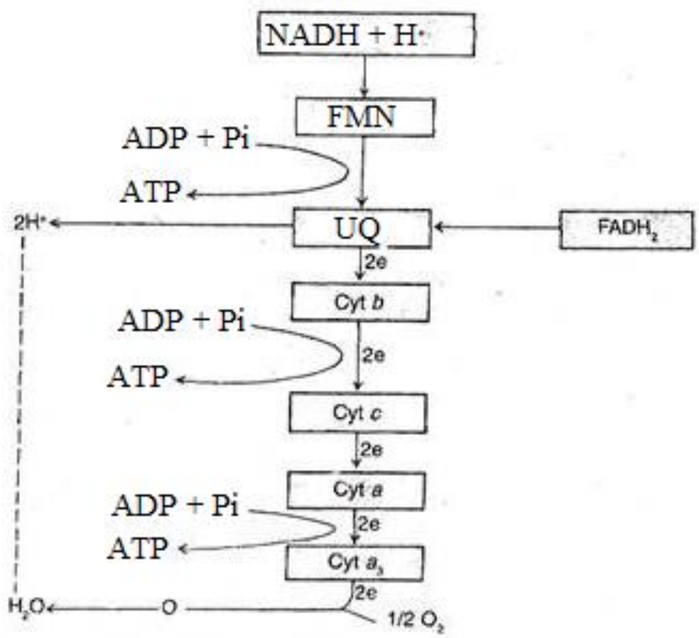


Fig.7.13 A simplified system of terminal oxidation and oxidative phosporylation

Significance of Krebs cycle:

1. Apart from serving as an energy-generating system, Krebs cycle yields several substances that figure as starting points for a number of biosynthetic reactions. Ordinarily Krebs cycle of respiration is considered catabolic in nature, but it provides a number of intermediates for

anabolic pathways. Therefore Krebs cycle is amphibolic (both catabolic and anabolic). A few examples are cited below:

(a) The synthesis of sucrose by way of glyoxylytic acid cycle is an instance in point. A slightly modified Krebs cycle leads to the formation of glyoxylate, malate, oxaloacetate, phosphoenol pyruvate and then by a reversed glycolytic pathway, sucrose is formed.

(b) There are two keto acids in Krebs cycle and on amination they yield the respective amino acids- Pyruvic acid —> alanine; Oxaloacetic acid —> aspartic acid; and oc-ketoglutaric acid —> glutamic acid.

The last of these opens up new pathways leading to the synthesis of glutamine, ornithine, proline, hydroxyproline, citruiline and arginine.

(c) Succinyl-CoA is the starting point for the biosynthesis of several porphyrins.

2. Krebs cycle is a common pathway of oxidative breakdown of carbohydrates, fatty acids, and amino acids.

7.12 ANAEROBIC RESPIRATION

Anaerobic respiration is synonymous with fermentation. It is also called intermolecular respiration.

Here the carbohydrates are degraded into two or more simple molecules without oxygen being used as oxidant. In anaerobic respiration (fermentation) the carbon-skeleton of glucose molecule is never completely released as CO_2 and in some it may not appear at all. It does not require mitochondria and is completed in cytoplasm.

The reason for believing that the two processes, fermentation and anaerobic respiration are identical, are:

1. Hexose sugar is respiratory substrates in both.
2. The principal end products are same (CO_2 and C_2H_gOH) in both the cases.
3. The same enzyme systems drive both the processes.
4. Pyruvic acid and acetaldehyde are formed as intermediates in both the processes.
5. Both the processes are accelerated by addition of phosphate.

But it must be mentioned that fermentation is an in vitro process, referring to an occurrence outside of a living system while anaerobic respiration is a cellular process, occurring in vivo. Also the energy produced during fermentation is totally lost as heat but the energy produced during anaerobic respiration, some of it at least, is trapped into ATP (Fig.7.14).

The term anaerobic respiration is often used in connection with higher organisms where it occurs in the roots of water-logged plants, muscles of animals and as supplementary mode of respiration in massive issues. Anaerobic respiration is the exclusive mode of respiration in some parasitic worms and micro-organisms (e.g., bacteria, moulds). In micro-organisms, the term fermentation is more commonly used where anaerobic respiration is known after the name of product like alcoholic fermentation, lactic acid fermentation.

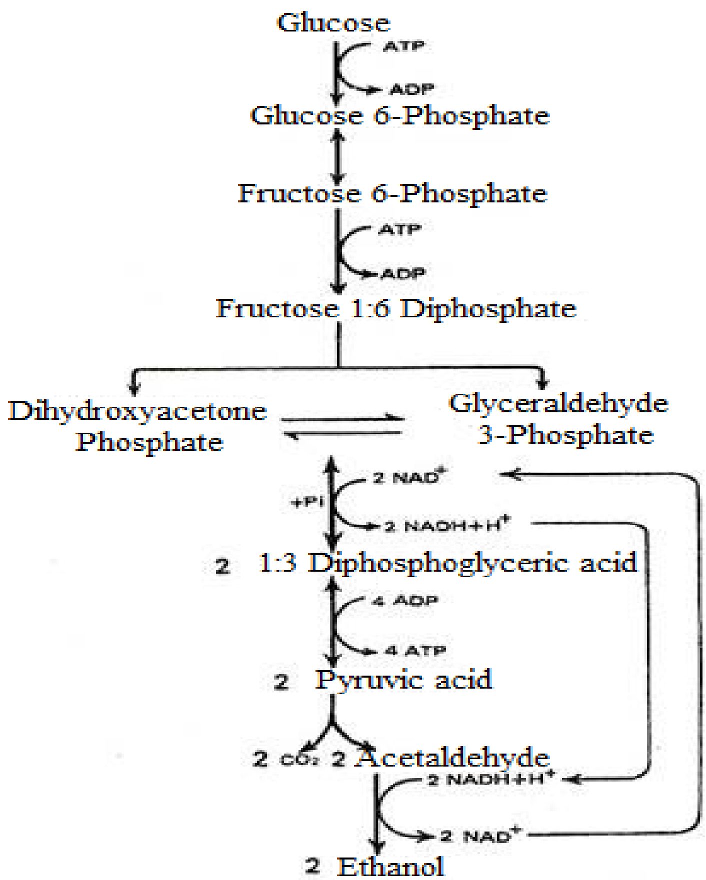


Fig.7.14 Schematic representation of alcoholic fermentation or anaerobic respiration yielding ethyl alcohol

Ethyl Alcohol Fermentation

It is quite common in fungi (e.g., Rhizopus, Yeast) and bacteria. Yeast can respire both aerobically and anaerobically. Anaerobic respiration occurs in sugary solution if the fungus is not in contact with atmosphere. It causes fermentation. In the presence of pyruvate decarboxylase and TPP (thiamine pyrophosphate), pyruvate is broken down to form acetaldehyde. Carbon dioxide is released.

$$\underset{\text{Pyruvate}}{2CH_3COCOOH} \xrightarrow[\text{decarboxylase}]{\text{Pyruvate}} \underset{\text{Acetaldehyde}}{2CH_3CHO} + 2CO_2$$

In the second step, acetaldehyde is reduced to alcohol by alcohol dehydrogenase. Hydrogen is obtained from NADH-, produced during oxidation of glyceraldehyde 3-phosphate to 1,3-diphospho- glvceric acid in glycolysis.

$$\underset{\text{Acetaldehyde}}{2CH_3CHO} + NADH \xrightarrow[\text{dehydrogenase}]{\text{Alcohol}} \underset{\text{Ethyl alcohol}}{C_2H_5OH} + NAD^+$$

Thus from 1 molecule of glucose, 2 molecules of pyruvic acid are formed and from 2 molecules of pyruvate (pyruvic acid) 2 molecules of ethyl alcohol and 2 molecules of $C0_2$ are produced. The overall equation is as follows:

$$C_6H_{12}O_6 \xrightarrow[\text{enzyme}]{\text{Zymase}} 2C_2H_5OH + 2CO_2 + 58\ \text{Kcal.}$$

Lactic Acid Fermentation

Less familiar in higher plants but quite common in animal tissue, this pathway leads to the formation of lactic acid. A NADH-requiring lactic dehydrogenase brings about this reaction. The NADH required for the reaction is produced in glycolysis.

$$CH_3COCOOH + NADH_2 \xrightarrow[\substack{\text{Dehydrogenase} \\ \text{FMN, } Zn^{2+}}]{\text{Lactic}} \underset{\text{Lactic Acid}}{C_3H_6O_3} + NAD^+$$

Alternate Anaerobic Respiration

The EMP pathway of glycolysis is no doubt the main anaerobic process but not the only channel of glucose metabolism. There are other pathways by which glucose is metabolised anaerobically in both plants and animal tissues. Two such systems discovered working in cells are Pentose phosphate pathway and Entner Duodoroff pathway.

Pentose Phosphate Pathway:

Variously called Direct Oxidation Pathway, Pentose Phosphate Pathway, Warburg-Dickens Pathway and Hexose Monophosphate Shunt, this metabolic pathway had been discovered through a number of experiments of Lippman, Warburg (1935) and Dickens (1938). Later Horacker (1955) and Racker (1954) worked out the sequence of events in the pathway.

Pentose Phosphate Pathway could be considered to proceed in two phases, a decarboxylative phase and a subsequent regenerative phase, in the first phase, the hexose is converted into a pentose. Two reactions, a decarboxylation and two dehydrogenations bring this about.

NADP functions as the coenzyme in both these reactions. In the second phase, there is reorganisation of the pentoses formed in phase I to produce a hexose. Therefore, in this pathway there is no cleavage of hexose to trioses as in glycolysis, and in PPP, NADP serves as the coenzyme and not NAD as in glycolysis.

Phase I. Decarboxylative phase:

a. Glucose-6-phosphate, which is the starting point for the operation of this pathway, is oxidised to phospho-gluconic acid by the mediation of NADP-linked glucose-6-phosphate dehydrogenase. Magnesium serves as an activator for this enzyme. The production of $NADPH_2$ marks the first dehydrogenation in this reaction.

$$\text{Glucose-6-phosphate} + \text{NADP} + H_2O \xrightleftharpoons[Mg^{++}]{\text{G-6-P dehydrogenase}} \text{6-Phosphogluconic acid} + NADPH_2$$

b. The 6-phosphogluconic acid is oxidised and decarboxylated by the NADP-linked 6-phosphogluconic acid dehydrogenase. The reaction is activated by Mg^{++}

$$\text{6-phosphogluconic acid} + \text{NADP} \xrightleftharpoons[\text{acid dehydrogenase, } Mg^{++}]{\text{6-phosphogluconic}} \text{Ribulose-5 phosphate} + NADPH_2 + CO_2$$

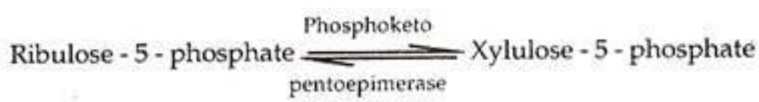
The production of $NADPH_2$ is the final dehydrogenation occurring along this pathway.

Phase II. Regenerative Phase:

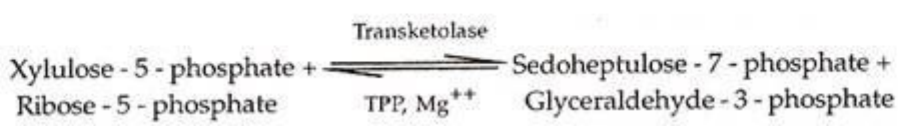
c. Here, ribulose-5-phosphate is converted to its aldopentose isomer, ribose-5-phosphate and is mediated by phosphoriboisomerase.

$$\text{Ribulose-5-phosphate} \xrightleftharpoons[\text{isomerase}]{\text{Phosphoribo}} \text{Ribose-5-phosphate}$$

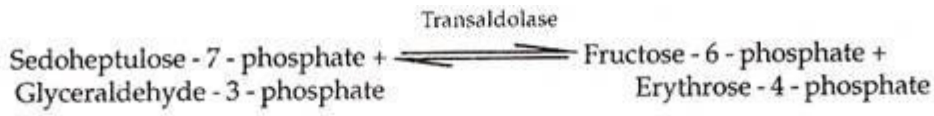
d. Some of the ribulose-5-phosphate formed in reaction 2 is isomerised to xylulose-5-phosphate, ketopentose. This is effected by phosphoketopento-epimerase.



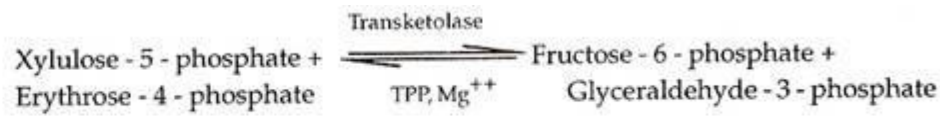
e. Ribose-5-phosphate and Xylulose-5-phosphate produced in reaction 3 and 4 form the substrates for this reaction. The enzyme, transketolase, transfers the ketol group from xylulose-5-phosphate to ribose-5-phosphate. As a result, a seven-carbon keto sugar, sedoheptulose-7-phosphate and a triose, glyceraldehyde-3-phosphate are formed. TPP and Mg^{++} serves as cofactors for this enzyme.



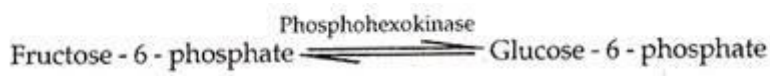
f. Sedoheptulose-7-phosphate and glyceraldehyde-3-phosphate are converted into fructoses-phosphate and erythrose-4-phosphate by the mediation of transaldolase.

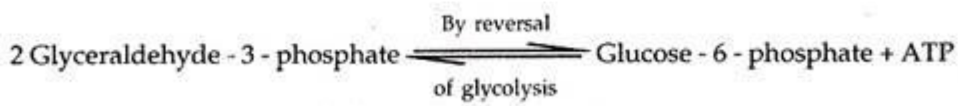


g. The erythrose-4-phosphate of reaction 6 and xylulose-5-phosphate of reaction 4 react through the agency of transketolase, forming fructose-6-phosphate and glyceraldehyde-3-phosphate.



Eventually, the fructose-6-phosphate formed in reactions f and g and glyceraldehyde-3-phosphate from reactions e and g, are converted into glucose-6-phosphate and this is further utilised to promote the pathway, until all of its carbon go off as $C0_2$. These reactions do not form part of the pathway.





Thus the PPP may be summarized as follows:

2Glucose – 6 – phosphate + 12 NADP + $6H_2O$ ——> 2 Glyceraldehyde – 3 – phosphate + 12 $NADPH_2$ + ATP + $6CO_2$

Significance of Pentose Phosphate Pathway

(a) The $NADPH_2$ produced drive a number of reactions leading to the conversion of glucose to sorbitol pyruvic acid to malic acid and phenylalanine to tyrosine.

(b) $NADH_2$ also plays a key role in the production of fatty acid and steroids.

(c) In this cycle several metabolically important intermediates such as ribose-5-phosphate and erythrose-4-phosphate are generated.

Entner Duodoroff Pathway:

In some bacteria like Azotobacter, the enzyme phosphofructokinase is absent. Such organisms naturally cannot phosphorylate glucose in the usual EMP pathway. They dissimilate glucose by a combination of pentose phosphate pathway and an aldolase type of reaction as in glycolysis.

Here, glucose is oxidized to 6-phosphogluconic acid, in the same manner as in reaction 1 of PPP. In the next step, 6-phophogluconic acid undergoes a dehydration and a conformational change, resulting in a oc-keto deoxysugar phosphate which is then cleaved into pyruvate and glyceraldehyde phosphate. GAP is converted to pyruvic acid. This pathway also produces 2 pyruvic acids from one molecule of glucose.

7.13 NITROGEN FIXATION

Nitrogen fixation is a process in which Nitrogen in the atmosphere is converted into ammonia NH_3. Nitrogen fixation, whether natural or synthetic, is essential for all forms of life because nitrogen is required to biosynthesize the basic building blocks of plants, animals and other life forms. For example, nucleotides are required for the synthesis of DNA and RNA and we should be very clear that the coenzyme NAD (Nicotinamide Adenine Dinucleotide) acts its role in metabolism (transferring electrons between molecules) as well as the synthesis of amino acids for proteins. Therefore, as part of the nitrogen cycle we can say that it is essential for agriculture and the manufacture of fertilizer.

7.13.1 Atmospheric Nitrogen Fixation

Nitrogen in its gaseous form (N_2) cannot be used by most of the living organisms. It has to be converted or 'fixed' to a more usable form through a process called fixation There are two ways by which nitrogen can be fixed to be useful for living things:

Biological Method of Nitrogen Fixation: Nitrogen gas (N_2) diffuses into the soil from the atmosphere, and species of bacteria convert this nitrogen to ammonium ions (NH_4^+), which can be used by plants. Legumes (such as clover and lupins) are often grown by farmers because they have nodules on their roots that contain nitrogen-fixing bacteria. The direct use of molecular nitrogen is known as asymbiotic nitrogen fixation and the indirect use of molecular nitrogen is known as symbiotic nitrogen fixation.

Through lightening: Lightning converts atmospheric nitrogen into ammonia and nitrate (NO_3^-) that enter soil with rainfall.

Industrially: People have learned how to convert nitrogen gas to ammonia (NH_3) and nitrogen-rich fertilizers to supplement the amount of nitrogen fixed naturally.

By means of two methods of atmospheric nitrogen fixation is carried out:-

(A) Non Biological or Physico-chemical Fixation

(B) Biological Nitrogen fixation

(A) Non Biological or Physico-chemical Fixation (By Electric Discharge and Rainfall)

Air, in which 79% nitrogen gas (N_2), is the major reservoir of nitrogen. The enormous energy of lightning breaks nitrogen molecules and enables their atoms to combine with oxygen in the air forming nitrogen oxides. These dissolve in rain, forming nitrates that are carried to the earth.

$$N_2 + O_2 \longrightarrow 2\ NO$$

$$2NO + O_2 \longrightarrow 2\ NO_2$$

$$2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$

These nitrite and nitrates react with many saline substances in soil and forming salts. These salts especially in form of calcium nitrite, calcium nitrate, potassium nitrite and potassium nitrate are ionized in the presence of water. These ionized salts are absorbed by the plant roots. It should be importantly noticed by us that generally main absorbed ionized nitrogen radicals are nitrates (NO_3^-) because nitrites are to be converted into nitrates by many processes. It is to be understood that atmospheric nitrogen fixation probably contributes some 5– 8% of the total nitrogen fixed with this process.

(B) Biological Nitrogen Fixation: Biological nitrogen fixation was discovered by the German agronomist Hermann Hellriegel and Dutch microbiologist Martinus Beijerinck. Biological nitrogen fixation (**BNF**) occurs when atmospheric nitrogen is converted to ammonia by an enzyme called a nitrogenase. The overall reaction for BNF can be given as:

$$\mathbf{N_2 + 8\ H^+ + 8\ e^- \rightarrow 2\ NH_3 + H_2}$$

The process is coupled to the hydrolysis of 16 equivalents of ATP and is accompanied by the co-formation of one molecule of H_2. The conversion of N_2 into ammonia occurs at a cluster called FeMoco, an abbreviation for the iron-molybdenum cofactor. The mechanism proceeds via a series of protonation and reduction steps wherein the FeMoco active site hydrogenates the N_2 substrate.

Biological nitrogen fixation is the process whereby atmospheric nitrogen is reduced to ammonia in the presence of nitrogenase. Nitrogenase is a biological catalyst found naturally only in certain microorganisms such as the symbiotic *Rhizobium* and *Frankia* or the free-living *Azospirillum* and *Azotobacter* and Cyanobacteria (BGA). Biological nitrogen fixation can be categorized into two types as Asymbiotic and Symbiotic.

7.13.2 Asymbiotic Nitrogen Fixation

Asymbiotic nitrogen fixation is carried out by means of free-living microbes (non-symbiotic microbes) including the cyanobacteria or blue-green algae (*Anabaena* and *Nostoc)* and genera such as *Azotobacter, Beijerinckia,* and *Clostridium.* In free-living microbes the nitrogenase-generated ammonium is assimilated into glutamate through the glutamine synthetase / glutamate synthase pathway. The microbial genes required for nitrogen fixation are widely distributed in diverse environments. Enzymes responsible for nitrogenase action are very susceptible to destruction by oxygen. For this reason, many bacteria cease production of the enzyme in the presence of oxygen. Many nitrogen-fixing microorganisms exist only in anaerobic conditions, respiring to draw down oxygen levels, or binding the oxygen with a protein such as leghemoglobin.

Among the living plant world, some free living bacteria, fungi and blue green algae (***Cyanobacteria***) are capable of fixing molecular nitrogen into utilizable form of N_2 i.e. NH_4. *Azatobactor veinlandi, Clostridium pasteurianum, Rhodospirullum rubrum, Chromatium, Nostoc, Anabaena, Rivularia* etc are the microbes having the ability to fix the molecular nitrogen. In recent years, the above said organisms are made available to farmers as bio-fertilizers. When the cultures of them are spread in the fields and allowed to grow, they enrich the soil with a lot of nitrogen as a natural fertilizer. One important aspect of it is to maintain moisture in the soil. Such living fertilizer renewable and enriches the soil all the time.

7.13.3. Symbiotic Nitrogen Fixation

The process which is performed by bacteria found in the nodules of leguminous plants and thereafter forming nitrogenous compounds available to the host plants known as symbiotic nitrogen fixation. Symbiotic nitrogen fixation occurs in plants that harbor nitrogen-fixing bacteria within their tissues. The best-studied example is the association between **legumes** and **bacteria** in the genus *Rhizobium*. On the other hand some other forms of bacteria are also being reported as symbiont in root nodules of many non-leguminous plants (*Frankia* as symbiont in the roots of *Casuarina* and *Alnus*). Each of these is able to survive independently (soil nitrates must then be available to the legume), but life together is clearly beneficial to both. Only together can nitrogen fixation take place. A symbiotic relationship in which both partners get benefits is called mutualism.

Symbiotic nitrogen fixation takes place by the activities of *Rhizobium*, which is pleomorphic bacteria, that enters the root of leguminous plant through the root hair and causes the nodule formation on the roots. There is a symbiotic relationship between *Rhizobium* and legumes.

7.14 CARBOHYDRATES

Carbohydrates are the most abundant class of organic compounds which are found in living organisms. They originate as products of photosynthesis, an endothermic reductive condensation of carbon dioxide requiring light energy and the pigment chlorophyll.

$$nCO_2 + n\,H_2O + \text{energy} \longrightarrow C_nH_{2n}O_n + n\,O_2$$

Carbohydrates can be defined as chemically as neutral compounds of carbon, hydrogen and oxygen. Carbohydrates form the basic constituent of diet of all living beings exist widely in animal and vegetable tissue. The composition of carbon, hydrogen and oxygen is in the ratio of 1:2:1. The empirical formula of carbohydrates is $C(H_2O)n$ where n usually ranges from 3–7.

Carbohydrates are present in sugars and starches. They make up parts of nucleotides (the energy currency of a cell, and the building blocks for genetic information). They are also present in some components of all cell membranes. They are the central components of energy producing pathways in biology. Carbohydrates may be defined as polyhydroxyl aldehydes or ketones or compounds which produce them on hydrolysis. The term sugar is applied to carbohydrates soluble in water to taste. Or Carbohydrates are that substance which on hydrolysis yields either ketones or aldehyde group. The carbohydrates are sometimes known as *saccharides.* Sacchrides comes from a *Greek* word Sacharon meaning Sugar, Glucose, Fructose, Sucrose, Starch, Cellulose, Glycogen are some of the common carbohydrates**.**

7.14.1Classification of Carbohydrates

The name carbohydrate literally means Hydrates of carbon. They are often known as saccharides which mean sugar.

There are a variety of interrelated classification schemes.

Based on functional groups:

1-Aldoses. The**y** contains the aldehyde group - Monosaccharides in this group are glucose, galactose, ribose, and glyceraldehyde.

2-Ketoses .They contains the ketone group - The major sugar in this group is fructose.

3-Reducing: They contain a hemiacetal or hemiketal group. Sugars include glucose, galactose, fructose, maltose, lactose

4-Non-reducing: They contain no hemiacetal groups. Sucrose and all polysaccharides are in this group.

Classification based on number of Carbons:

Monosaccharides can be further classified by the number of carbons present.

Hexoses (6-carbons) are by far the most prevalent.

	Number of Carbons	
Three = Triose	**Five = Pentose**	**Six = Hexose**
Glyceraldehyde	Ribose	**Glucose**
		Galactose
		Fructose

They are broadly classified into 3 groups based on sugar unit:-

1. Monosaccharides

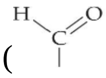
2. Oligosaccharides

3. Polysaccharides

Mono and oligosaccharides are sweet to taste, crystalline in character and soluble in water, hence they are commonly known as sugar.

1-Monosaccharides

Mono means one. Monosaccharides are a simple group of carbohydrates. The general formula is $C_n(H_2O)_n$..These contain a single carbon chain Monosaccharides are divided into two categories based on the functional group and number of a carbon atom.

Sugars which have aldehyde (

) group are called aldoses (e.g.: glyceraldehydes, glucose.) and sugars with keto group arecalled ketoses (e.g: dihydroxy acetone, fructose). Depending on the number of carbon atoms monosaccharides are named as

1. Triose (C3)
2. Tetrose (C4)
3. Pentose (C5)
4. Hexose (C6)

1. Triose (C3): These have three carbon atom.

Glyceraldehyde and dihydroxy acetone are the simplest carbon hydrates with three carbon compounds. Glceraldehyde have aldolase group and dihydroxy acetone ketone group.

H
|
C=O
|
CHOH
|
CH_2OH

Glyceraldehyde

2. Tetrose (C4): These have four carbon atom Erythrose (C4H8O4) is an important carbohydrate, whose structure is as follows:

CHO
|
CHOH
|
CHOH
|
CH_2OH

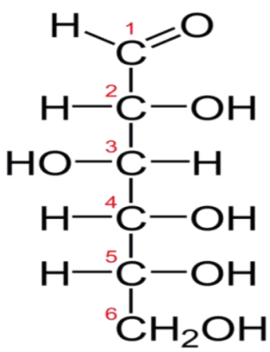
Erythrose

3. Pentose (C5):-These have 5 carbon atoms. Ribulose and Xylose are common pentoses. Riboses have aldehyde while xylose has ketone group.

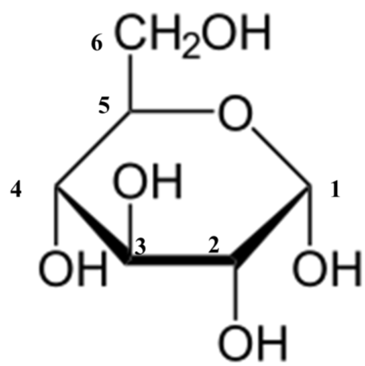
CHO
|
CHOH
|
CHOH
|
CHOH
|
CH_2OH

Ribose

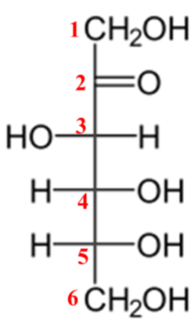
4. Hexoses (C6):-Hexoses have common formula $C_6H_{12}O_6$ and commonly meet with in plants in free conditions. Glucose and fructose are more common carbohydrates. **Glucose** is aldohexose while **fructose** in a keto hexose.



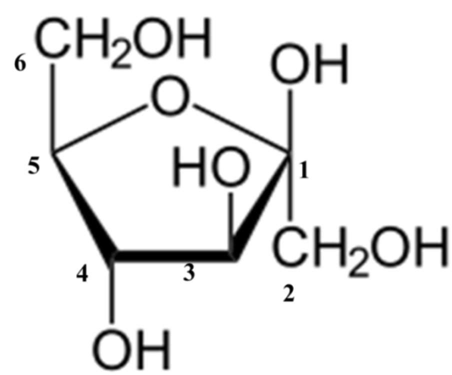
Glucose (Fischer projections)



Glucose (Haworth projections)



Fructose (Fischer projections)



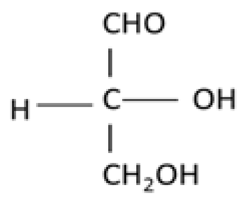
Fructose (Haworth projections)

Note - Fischer projections and **Haworth projections of structure**

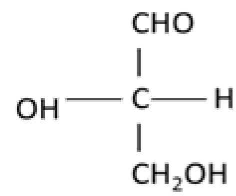
Fisher projections show sugars in their open chain form. In this type, the carbon atoms of a sugar molecule are connected vertically by solid lines, while carbon-oxygen and carbon-hydrogen bonds are shown horizontally.

Haworth projections are often used to depict sugars in their cyclic forms. It is a common way to draw a structural formula which represents the cyclic structure of monosaccharides with a simple three-dimensional perspective

Stereoisomers



D(+)Glyceraldehyde



L(-) Glyceraldehyde

Stereoisomers compounds have a same structural formula but differ in the spatial configuration. While writing the molecular formula of monosaccharides, the spatial arrangements of H and OH groups are important, since they contain asymmetric carbon atoms. Asymmetric carbon means four different groups are attached to the same carbon. The reference molecule is glyceraldehyde which has a single asymmetric carbon.

The number of possible sterioisomers depends on the number of asymmetric carbon atoms by the formula 2n where n is the number of asymmetric carbon atoms.

Reference carbon atom of sugars

The configuration of H and OH at the second carbon of glyceraldehyde makes two mirror images denoted as D and L form. All monosaccharides are derived from glyceraldehyde by successive addition of carbon atoms. Therefore the penultimate carbon atom is the reference carbon atom for naming the mirror images. This is also referred to as absolute configuration.

Optical activity

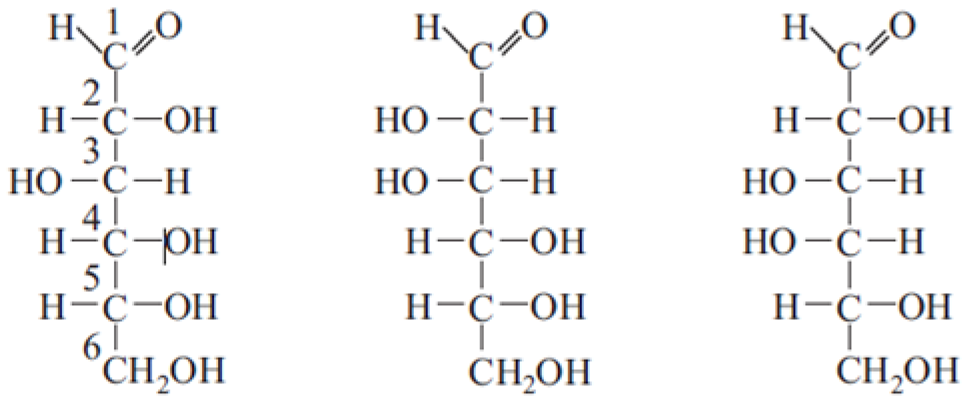
Optical activity is caused by due to the presence of asymmetrical carbon atom. When a beam of plane polarized light is passed through a solution of carbohydrates, it will rotate the light either to right or to left. Depending on the rotation, molecules are called dextrorotatory (+) (d) or levorotatory (–).

Racemic mixture

If D and L- isomers of a carbohydrate are present in unequal concentration, it is known as racemic mixture or DL mixture. The racemic mixture does not exhibit any optical activity because dextro- and levorotatory activities cancel each other.

Epimers

Epimer refers to one of a pair of stereoisomers. In this, sugars are different from one another, only in configuration with regard to the single carbon atom, other than the reference carbon atom, they are called Epimers. Example Glucose and Mannose are an epimeric pair because they differ only with respect to C2. Similarly, galactose is epimer of glucose which differs at C4.



D-Glucose D-Mannose D-Galactose

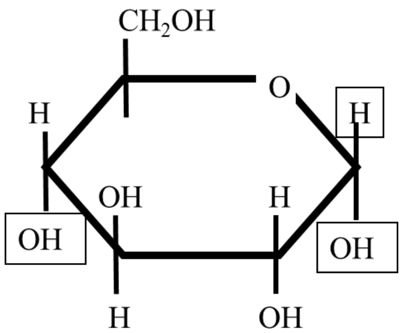
Anomers

An anomer is a type of stereoisomer and epimer found in carbohydrate chemistry. When D-glucose is crystallized at room temperature and a fresh solution is prepared, its specific rotation of polarized light is +112°; but it changes to +52.5° after 12-18 hours. If initial crystallization is taking place at 98° C and thensolubilized, the specific rotation is found to be +19°, which also changesto+52.5° within few hours. This change in rotation with time is called

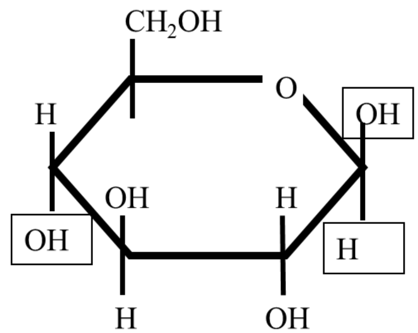
Mutarotation

D-glucose has two anomers, alpha and betaform. The alpha and beta form are produced by the spatial configuration withreference to the first carbon atom in aldoses and second carbon in ketoses. Therefore these carbon atoms are called anomeric carbon atoms. α-D-glucose has specific rotation of +112° and β-D-glucose has specific rotation of +19°. Both undergo mutarotation and at equilibrium one-third molecules are alpha type and two-thirdare beta variety to get the specific rotation +52.5°.

glucose



α-D-glucose



β-D-glucose

Disaccharides

When two monosaccharides are combined together with the elimination of a water molecule it is called disaccharide. Monosaccharides are combined by a glycosidic bond. They are crystalline, water- soluble and sweet to taste. The disaccharides are two types:

1. **Reducing disaccharides** with free aldehyde or keto group e.g. maltose lactose
2. **Non –reducing disaccharides** with no free aldehyde or keto group. e.g. sucrose, trehalose

Disaccharide	Description	Component monosaccharides
Sucrose	Common table sugar	glucose α1 → 2 fructose
Maltose	Production of starch hydrolysis	glucose α1 → 4 glucose
Trehalose	Found in fungi	glucose α 1 → 1glucose
Lactose	Main sugar in milk	galactose β1 → 4glucose
Melibiose	Found in legumes	galactose β1 → 6 glucose

Sucrose

Sucrose also called saccharose, is ordinary table sugar refined from sugar cane or sugar beets. Sucrose is not a reducing sugar. This is because of the glycosidic linkage inolves first carbon of glucose and second carbon of fructose, and hence there are no free reducing groups. When sucrose is hydrolyzed the resulting products have reducing property. Hydrolysis of sucrose (optical rotation +66.5°) will produce one molecule of glucose (+52.5°) and one molecule of fructose (92°). Therefore the products will change the dextrorotation to levorotation, or the plane of rotation is inverted. An equimolecular mixture of glucose and fructosethus formed is called invert sugar.

Polysaccharides

Polysaccharides are polymerized products of many monosaccharide units. They may be homo or hetero polysaccharides. Many polysaccharides, unlike sugars, are insoluble in water. Dietary fiber includes polysaccharides and oligosaccharides that are resistant to digestion and absorption in the human small intestine but which are completely or partially fermented by microorganisms in the large intestine.

Homopolysaccharides

Which on hydrolysis yield only a single type of monosaccharide. They have only one type of monosaccharide units. Thus **glucans** are polymer of glucose where as **fructosans** are polymer of fructose.

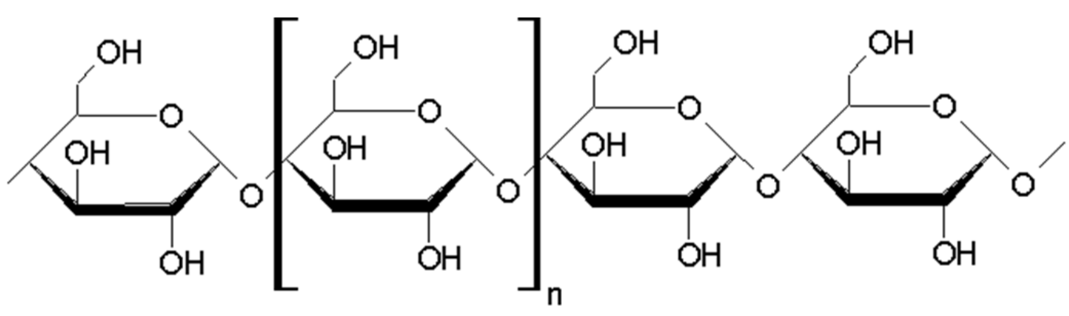
Heteropolysaccharides

They yield a mixture of a few monosaccharides or their derivatives on hydrolysis. Example- glycoproteins.

Starch

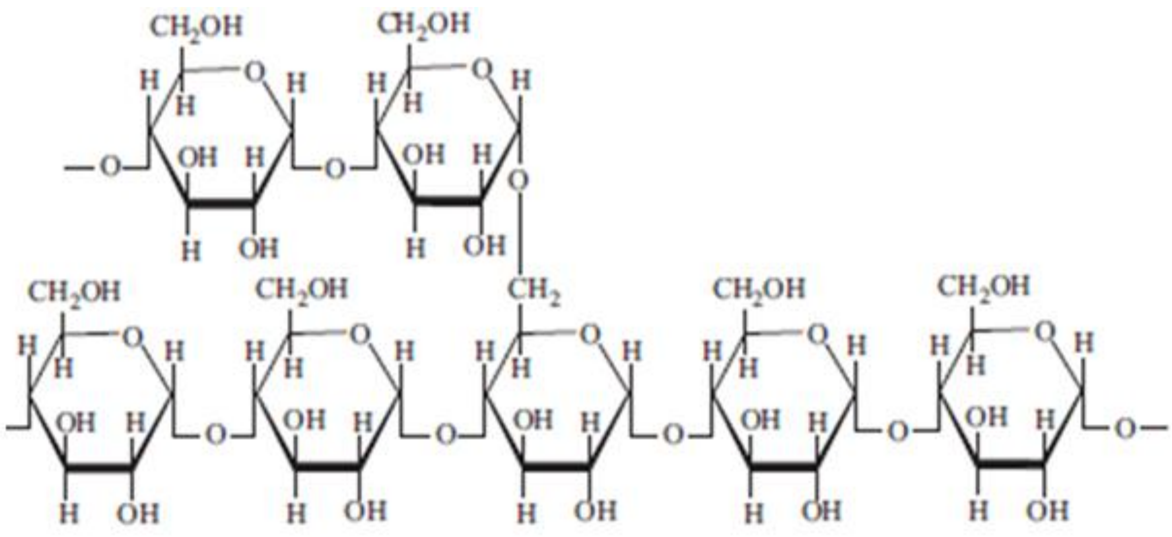
Starch or amylum is the major form of stored carbohydrate in plants. Starch is composed of a mixture of two substances: amylose which is a linear polysaccharide, and amylopectin that is a highly branched polysaccharide. Both forms of starch arepolymers of α-D glucose which is joined by 1, 4-alpha bonds. Natural starches contain 10-20% amylose and 80- 90% amylopectin. Amylose forms a colloidal dispersion in hot water (which helps to thicken gravies) whereas amylopectin is completely insoluble. Starch consist two polysaccharides component water soluble amylase and a water insoluble amylopectin.

Amylose molecules consist typically of 200 to 20,000 D-glucose units held by(α 1→4)glycosidic linkage.



Amylose

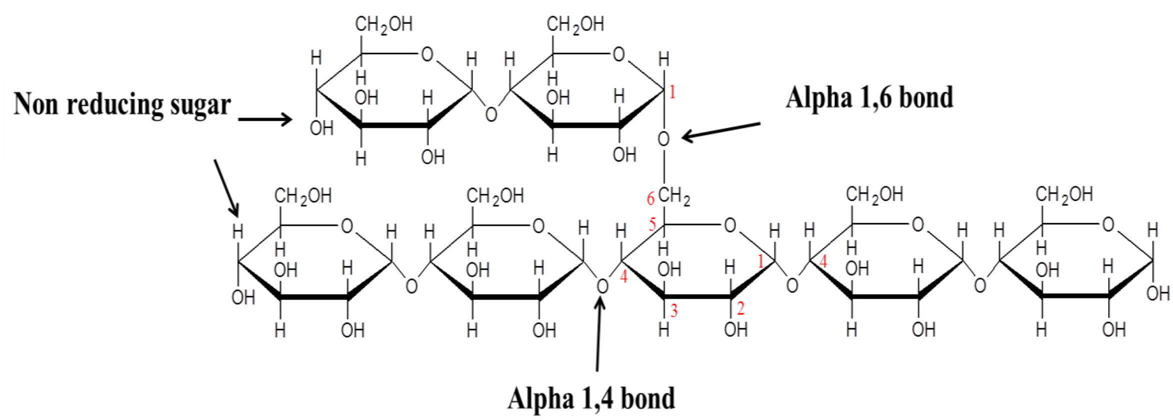
Amylopectin is a branched chain with α 1→6 glycosidic bond at the branching points and α 1→4 linkage everywhere else.



Amylopectin

Glycogen

Glucose is stored as glycogen in animal tissues by the process of glycogenesis. The excess glucose which cannot be stored as glycogen or used immediately for energy is converted to fat. Glycogen is a polymer of α D-Glucose which is identical to amylopectin, but the branches in glycogen are shorter (about 13 glucose units) and more common. The glucose chains are organized globularly and look like branches of a tree originating from a pair of molecules of glycogenin which an enzyme and convert glucose to glycogen. Glycogen is easily converted back to glucose to give energy.

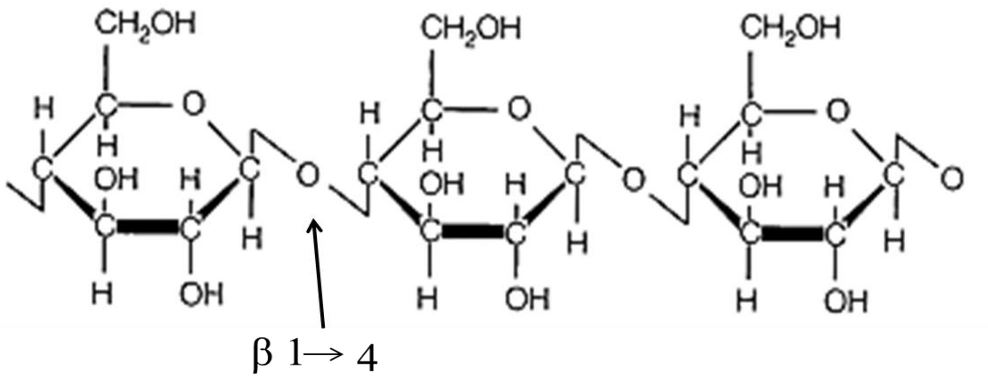


Glycogen

Cellulose

Cellulose is a polymer of β-D-Glucose joined by β 1, 4 bond. It in contrast to starch is oriented with –CH2OH groups alternating above and below the plane of the cellulose molecule thus producing long, unbranched chains. $C_6H_{10}O_5$ is the general formula of cellulose. The absence of side chains allows cellulose molecules to lie close together and form rigid structures.

It is the major structural material of plants. The cotton is almost pure cellulose. Cellulose can be hydrolyzed to its constituent glucose units by microorganisms that are found in the digestive tract of termites and ruminants. Cellulose could be may be modified by nitric acid (HNO3) to replace all the hydroxyl groups with nitrate groups (-ONO2) resulting cellulose nitrate (nitrocellulose or guncotton) which is an explosive. Pyroxylin is partially nitrated cellulose that is used in the manufacture of collodion, plastics, lacquers, and nail polish.



Cellulose

Heteropolysaccharides

Heteropolysaccarides contain two or more different kind of monosaccharides. Generally, they provide extracellular support for organisms of all kingdoms. They give protection, specific shape, and support to cells, tissues and organs. Together with fibrous proteins, like collagen, elastin, fibronectin, laminin and others, heteropolysaccharides are the most important components of the extracellular matrix. Example; Hyaluronic acid, condroitin sulfates and dermatansulfates. They are found in the extracellular matrix. The heteropolysaccharides usually are made up by the repetition of a disaccharide unit of an aminosugar and an acid sugar.

Heteropolysaccharides combine with proteins to form proteoglycans, glycosaminoglycans or mucopolysaccharides. Such heteropolysaccharidesarefound abundantly inmucous secretions. They are involved in diverse functions: structural, water metabolism regulation cellular cement, biological sieve, biological lubricant, docking sites for growth factors, among other functions.

Hyaluronic Acid (Hyaluronate): It acts as lubricant in the synovial fluid of joints, provides consistency to vitreous humor, contributes to tensile strength and elasticity of cartilages and tendons.

Chondroitin Sulfates: It contributes to tensile strength and elasticity of cartilages, tendons, ligaments and walls of the aorta.

Dermatan sulfate: It is found mainly in skin, but also is present lungs, vessels, and heart. It considered being involved in coagulation and vascular diseases and other conditions.

Keratan sulfate: Present in the cornea, cartilage bone and a variety of other structures as nails and hair.

7.14.2 Properties

Physical Properties of Monosaccharides

Most monosaccharides have a sweet taste (fructose is sweetest; 73% sweeter than sucrose).

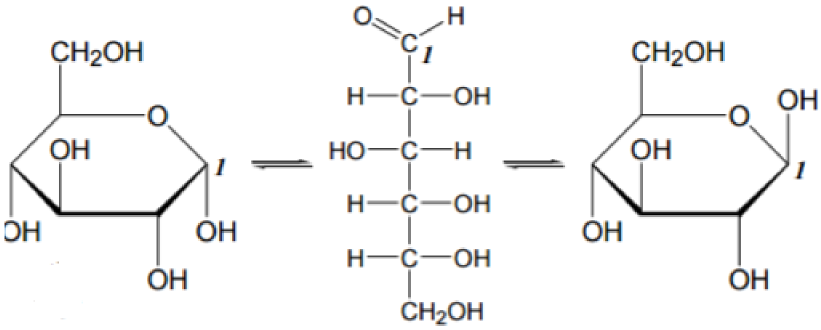
They are solids at room temperature.

They are extremely soluble in water: – Despite their high molecular weights, the presence of large numbers of OH groups make the monosaccharides much more water soluble than most molecules of similar MW.

Glucose can dissolve in minute amounts of water to make syrup (1 g /1 ml H2O).

Chemical Properties of Monosaccharides

Monosaccharides do not usually exist in solution in their "open-chain" forms: an alcohol group can add into the carbonyl group in the same molecule to form a pyranose ring containing a stable cyclic hemiacetal or hemiketal.



α-D-glucose 36% D-glucose 0.02% β-D-glucose 64%

Oxidation of Monosaccharides

Aldehydes and ketones that have an OH group on the carbon next to the carbonyl group react with a basic solution of Cu2+ (Benedict's reagent) to form a red-orange precipitate of copper (I) oxide (Cu2O).

• Sugars that undergo this reaction are called reducing sugars. (All of the monosaccharides are reducing sugars.)

Reducing sugar + Cu^{2+} ⟶ oxidation product + Cu2O (red-orange precipitate)

Deep blue solution

Biological role of Carbohydrates

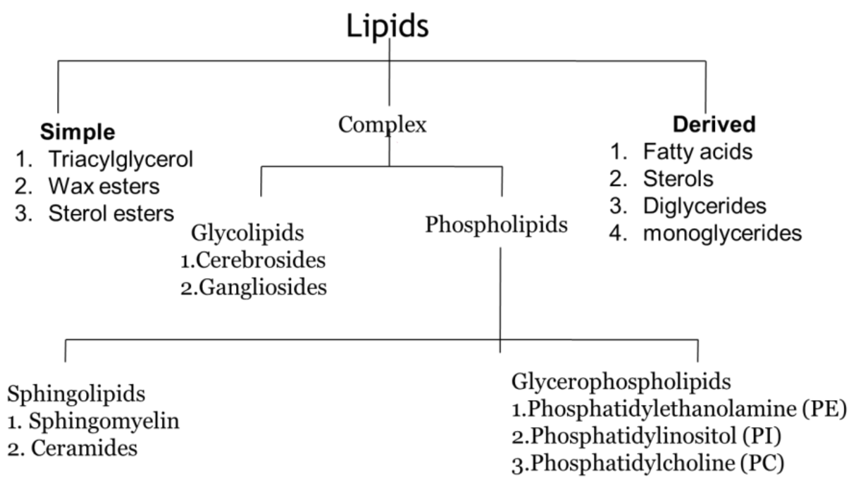
1. Carbohydrate like glucose is source of energy for the body. Glucose is a simple sugar and found in many basic foods.
2. Carbohydrate are starting material in biosynthesis
3. Carbohydrates may be soluble and insoluble. The insoluble carbohydrate which is like fiber promotes regular bowel movement, regulates the rate of consumption of blood glucose, and also helps to remove excess cholesterol from the body.
4. To provide immediate source of energy, glucose is broken down during the process of cellular respiration, which produce ATP, the energy currency of the cell.
5. Carbohydrates are an important part of the human nutrition.
6. Since carbohydrates are main source of energy, they are essential to all animal life.
7. Carbohydrates are immediate source of energy while lipids are long-term source of energy Carbohydrates work as energy stores of animals and plants.
8. Carbohydrates are instant source of energy while lipids are long-term source of energy.
9. Glucose is a free sugar and circulates in blood. Therefore it is an important substance for normal cell functioning.
10. Regulation of glucose metabolism is l for survival. Usually carbohydrates content of most of the plant is about 60-80% of its dry mass.
11. In plants they are used for storage of energy in the form of starch.
12. Cellulose is a polysaccharide which is an important structural component in the cell wall of plants.
13. Sucrose, a disaccharide is formed by photosynthesis and is transported internally.
14. Carbohydrates are an important component of diet in animals.
15. Carbohydrates act as fuel to physical body parts on daily basis.
16. They help in breakdown of fatty acids and prevent ketosis.
17. They minimize the use of proteins for energy.
18. They also act as flavor and sweeteners.

7.15LIPIDS

The word lipid is derived from a greek word "lipos" which means FAT. Lipids are biological molecules and commonly known as fats. They are largely hydrocarbon in composition. They represent highly reduced forms of carbon. Lipids can be defined as either the esters of fatty acids and glycerol, or as fatty acid triglycerides. They yield large amounts of energy upon oxidation in metabolism in the cells. They act as building blocks of the structure and function of living cells. Examples of lipids include fats, oils, waxes, certain vitamins, hormones and most of the non-protein membrane of cells. Lipids are non-polar and are thus soluble in non polar environments like in chloroform but not soluble in polar environments like water.

7.15.1 Classification

Lipids can be classified in following major groups based on structure



A-Simple lipids

They are esters of fatty acids with various alcohols. Simple lipids belong to a heterogeneous class of nonpolar compounds, mostly insoluble in water. They are but soluble in nonpolar organic solvents such as chloroform and benzene.

They include:

1-**Fat and oils**: They are esters of glycerol and fatty acids. Fatty acids may be saturate or unsaturated. They may be same or mixed. Fats are also known as triglycerides because all the three hydroxyl groups of glycerol are esterified. Oils are fats in the liquid state.

2-**Waxes**-They are esters of long-chain alcohols and fatty acids. The alcohol may contain from 12-32 carbon atoms. Many of the waxes are used in ointments, hand creams, and cosmetics. Paraffin wax is used for making some candles. Ear wax is a mixture of phospholipids and esters of cholesterol.

The waxes with their component alcohols and fatty acids are listed in the table on the left.

3- **Ceramides**-They are amides of fatty acids with long-chain di- or trihydroxy bases containing 12–22 carbon atoms in the carbon chain: e.g. sphingosine.

4- **Cholesteryl esters-** They are dietary lipids and are esters of cholesterol and fatty acids.Cholesteryl esters have a lower solubility in water due to their increased hydrophobicity. They are hydrolyzed by pancreatic enzymes, cholesterol esterase resulting free fatty acids and cholesterol. They have been found associated with atherosclerosis. Example- Cholesteryloleate

B- Complex lipids

Lipids which contain parts other than or including fatty acids and glycerol are called complex lipids. They are found in most cell membranes, in blood platelets and especially brain tissue.
Example-

1. Phosphatidic acid that is diacylglycerol esterified to phosphoric acid.
2. Phosphatidylcholine that is phosphatidic acid linked to choline, also called lecithin.
3. Phospholipids that is glycerol esters of fatty acids.
4. Phosphoric acid and other groups containing nitrogen.
5. Phosphatidylethanolamine.
6. phosphatidylserine;
7. posphatidylinositol;
8. phosphatidylacylglycerol in which more than one glycerol molecule is esterified to phosphoric acid: e.g. cardiolipin and diphosphatidylacylglycerol;
9. gangliosides that are glycolipids that are structurally similar to ceramide polyhexoside and also contain 1-3 sialic acid residues; most contain an amino sugar in addition to the other sugars;
10. sphingolipids, derivatives of ceramides;
11. sphingomyelin that is ceramide phosphorylcholine;
12. cerebroside: they are ceramide monohexoside that is ceramide linked to a single sugar moiety at the terminal hydroxyl group of the base);
13. ceramide di- and polyhexoside that is linked respectively to a disaccharide or a tri- or oligosaccharide;
14. Cerebroside sulfate that is ceramide monohexoside esterified to a sulfate group.

C- **Derived lipids**

They are produced from simple and compound lipids through the process of hydrolysis.
They include:

1. Fatty acids and alcohols
2. Fat soluble vitamins A, D, E and K;
3. Sterols, e.g., Cholesterol.

Cholesterol is the precursor to our sex hormones and Vitamin D. Vitamin D is formed by the action of UV light in sunlight on cholesterol molecules that have "risen" to near the surface of the skin. Our cell membranes contain a lot of cholesterol, in between the phospholipids, to help keep them fluid. Excess cholesterol levels can exceed the saturation level in bile, causing gallstones to form. Gallstones are almost all cholesterol with a small amount of minerals, like calcium. Maximum cholesterol levels in the blood would be 220 mg/dl of blood plasma.

7.15.2 Properties of Lipids

Physical Properties of Fatty Acids

1. The physical properties of fatty acids are largely determined by the length and degree of unsaturation of the hydrocarbon chain.
2. The longer the chain and the fewer the double bonds, the lower are the solubility in water, and higher is the melting point.
3. Addition of double bonds decreases the melting point whereas; increasing the chain length increases the melting point. For example; 4:0 MP -7.9 C, 12:0 MP 44.2 C, 16:0 MP 62.7 C, 18:1 MP 10.5 C, 18:2 MP -5.0 C, 18:3 MP -11 C.
4. Trivial names of fatty acids refer to the natural sources of derivation: eg

Lauric (12:0) isolated from seed fat of Lauraceae
Myristic (14:0) –seed fat Myristaceae
Palmitic (16:0) –seed fat of palmae
Oleic (18:1) –seed fat of olive oil.

Chemical Properties of Lipids

1. Acid number: The acid number is defined as the mg of KOH necessary to neutralize the free fatty acids present in 1g of fat or oil. The acid number tells the quantity of free fatty acid present in a fat. A high acid value indicates a state oil or fat stored under improper conditions. The acid value is important because it measures hydrolytic rancidity. FFA= ml alkali * N of alkali * 28.2 mg/sample weight

2. Saponification: Saponification is the process of breaking down or degrading a neutral fat into glycerol and fatty acids by treatment of with alkali. Saponification number is defined as the mg of KOH required to saponify 1g of fat. Saponification number=(S-B) *N*56.1/sample weight.

3. Iodine Number: It is a measure of thedegree of unsaturation, the number of carbon-carbon double bonds in relation to the amount of fat or oil. It is defined as the g iodine absorbed per 100g of thesample. Iodine number = (B-S)*N*12.69/sample weight

4. Peroxide value: Peroxide value is the measures the degree of lipid oxidation in fats and oils. It isused to check rancidity in unsaturated fats and oils. Peroxide value is the number of milli equivalents of peroxide per kg fat. It is a measure of the formation of peroxide or hydroxide groups that are initial products of the lipid oxidation. Peroxide value=(S-B)*N*1000/sample weight.

5. Riechert Messel Number: Riechert Messel Number is a mea the amount of H2O soluble volatile fatty acids. It is defined as the number of milliliters of 0.1 N alkali necessary to neutralize the volatile H2O soluble fatty acids in a 5g sample of fat.

6. Polenkee number: Polenkee number refers the required the amount of volatile insoluble fatty acids. It can be defined as the no: of millilitres of 0.1N alkali necessary to neutralize the volatile H_2O insoluble fatty acids which are present in the5g sample.

7. Hydrolysis: When fats react with water, it results in the splitting of some of the fatty acids from the oil or fat, yielding some free fatty acids, monoglycerides and diglycerides. It is accelerated by high temperatures & pressures & an excessive amount of water.

8. Hydrogenation: Hydrogenation is used to make hydrogenated fats are unnatural fats that are detrimental to health. Hydrogenation (or, more accurately, "partial hydrogenation") is the forced chemical addition of hydrogen into omega-6 polyunsaturated oils to make them hard at room temperatures, The rate of hydrogenation depends on nature of thesubstance to be hydrogenated, type and concentration of the catalyst, concentration of hydrogen, temperature, pressure etc.

9. Isomerization: Isomerization is the process by which one molecule is transformed into another molecule that has exactly the same atoms, but different arrangement. The two important types of isomerism are Geometric & Positional isomerism. Geometrical isomerism: -

(i) In geometrical Isomerism a double bond can have two configurations;- Cis or Trans. When the H_2 atoms are on the same side of the carbon chain, the arrangement is called Cis. H_2 atoms are on opposite sides of the carbon chain, the arrangement is called trans. Natural fats & oils contain cis form.

(ii) Positional Isomerism: In positional Isomerism unsaturated fatty acid can be isomerised in acid or alkaline conditions or by high temperatures where the double bond move from one position to another. Hydrogenation process can cause shifts double bonds in the fatty acid chains causing cis - transisomerisation. Cis isomers found in food fats & oils & trans isomers occur in fats from remnants. Most Trans isomers result from the partial hydrogenation of fats & oils.

10. Esterification: Esterification is the reverse of hydrolysis which combines free fatty acids with glycerol to form triglycerides. Mono & diglycerides are produced by esterification. Monoglycerides are important emulsifying agents in food products. Emulsifying agents are called emulsifiers which are made either by alcoholysis or by direct esterification. In direct esterification, fatty acids & polyalcohol are reacted together under controlled conditions to form esters.

11. Interesterification: It takes place when the fatty acids have been moved from one triglyceride molecule to another This process is also referred to as Randomization, rearrangement or modification. It is used for processing edible fats & oils to produce confectionery or coating fats, margarine oils, cooking fats, frying fats, shortenings & other special application products.

12. Oxidation: The oxidation reaction of an oil or fat occurs with O_2 in the air, and with the food at the double bonds or points of unsaturation. This reaction affects the flavour of the fat. The rate of oxidation increases with increase in temperature, exposure to O_2, presence of light& pro-oxidants like Metal Cu. Oxidation which takes place by air at room temperature is referred to as Autoxidation.

13. Polymerization: Excessive oxidation of fatty acid results Polymerization. Thedeepfrying of foods at temperatures ranging from 325º F -375º F lead to polymerization due to heat stress, oxidation & presence of the radical & polar catalyst. The rate of polymerization increases with the amount of unsaturation & viscosity of fat or oil.

14. Halogenation: The halogens include Chlorine, Bromine & Iodine can readily add to the double bonds of unsaturated fatty acids. In halogenation, measured quantities of iodine are added to measure quantities of fats or oils to determine the average degree of unsaturation of fat or oil. This results in iodine number, an important analytical measurement.

Biological role of lipids:

Lipids perform several biological functions:

1. Lipids are storage compounds. The triglycerides serve as reserve energy of the body.
2. Lipids are important component of cell membranes structure in eukaryotic cells.
3. Lipids regulate membrane permeability.
4. They serve as source for fat soluble vitamins like A, D, E, K.
5. They act electrical insulators to the nerve fibers, where the myelin sheath contains lipids.
6. Lipids are components of some enzyme systems.
7. Some lipids like prostaglandins and steroid hormones act as cellular metabolic regulators.
8. Cholesterol is found in cell membranes, blood, and bile of many organisms.
9. As lipids are small molecules and are insoluble in water, they act as signaling molecules.
10. Layers of fat in the subcutaneous layer, provides insulation and protection from cold. Body temperature maintenance is done by brown fat.
11. Polyunsaturated phospholipids are important constituents of phospholipids; they provide fluidity and flexibility to the cell membranes.
12. Lipoproteins that are complexes of lipids and proteins, occur in blood as plasma lipoprotein, they enable transport of lipids in aqueousenvironment, and their transport throughout the body.
13. Cholesterol maintains fluidity of membranes by interacting with lipid complexes.
14. Cholesterol is the precursor of bile acids, Vitamin D and steroids.
15. Essential fatty acids like linoleic and linolenic acids are precursors of many different types of ecosanoids including prostaglandins, thromboxanes. These play animportant role in pain, fever, inflammation and blood clotting.

7.16 PROTEINS

Proteins are the macromolecules responsible for the biological processes in the cell. They consist at their most basic level of a chain of amino acids, determined by the sequence of nucleotides in a gene. Depending on the amino acid sequence (different amino acids have different biochemical properties) and interactions with their environment, proteins fold into a

three-dimensional structure, which allows them to interact with other proteins and molecules and perform their function. They are naturally occurring polypeptides made up of 40 to 4000 amino acids. Proteins serve many functions in living systems. More than 28 million proteins are known.
Examples of the Diverse Functions of Proteins in Living Systems:

Structural Proteins -These proteins impart strength to biological structures or protect organisms from their environment. For example, collagen is the major component of bones, muscles, and tendons; keratin is the major component of hair, hooves, feathers, fur, and the outer layer of skin.

Protective Proteins- Snake venoms and plant toxins are proteins that protect their owners from predators.

Blood-clotting proteins protect the vascular system when it is injured. Antibodies and peptide antibiotics protect us from disease.

Enzymes- Enzymes are proteins that catalyze the reactions that occur in cells.

Hormones -Some hormones, compounds that regulate the reactions that occur in living systems, are proteins.

Proteins with Physiological Functions-These proteins include those that transport and store oxygen in the body, store oxygen in the muscles, and contract muscles.

7.16.1 Classification

Different methods of protein classification have been proposed, but currently none of them is universally valid. Below, some examples based on chemical composition,structure, functions, and solubility in different solvents.

Protein classification based on chemical composition

On the basis of their chemical composition, proteins may be divided into two classes: simple and complex.

1. Simple proteins: Also known as homoproteins, they are made up of only amino acids. Examples are plasma albumin, collagen, and keratin.

2. Conjugated proteins: Sometimes also called heteroproteins, they contain in their structure a non-protein portion. Three examples are glycoproteins, chromoproteins, and phosphoproteins.

(a) Glycoproteins- They are proteins that covalently bind one or more carbohydrate units to the polypeptide backbone.Typically, the branches consist of not more than 15-20carbohydrate units, where you can find arabinose, fucose (6-deoxygalactose), galactose, glucose, mannose, N-acetylglucosamine (GlcNAc, or NAG), and N-acetylneuraminic acid (Neu5Ac or NANA). Examples of glycoproteins are: glycophorin, the best known among erythrocyte membrane glycoproteins fibronectin, that anchors cells to the extracellular matrix through interactions on one side with collagen or other fibrous proteins, while on the other side with cell membranes; all blood plasma proteins, except albumin; immunoglobulins or antibodies.

(b) Chromoproteins -They are proteins that contain colored prosthetic groups.
Typical examples are: hemoglobin and myoglobin, which bind, respectively, one and four heme groups; chlorophylls, which bind a porphyrin ring with a magnesium atom at its centre; rhodopsins, which bind retinal.

(c) Phosphoproteins- They are proteins that bind phosphoric acid to serine and threonine residues. Generally, they have a structural function, such as tooth dentin, or reserve function, such as milk caseins (alpha, beta, gamma and delta), and egg yolk phosvitin.

Protein classification based on shape

On the basis of their shape, proteins may be divided into two classes: fibrous and globular. They have primarily **mechanical and structural functions**, providing support to the cells as well as the whole organism. These proteins are insoluble in water as they contain, both internally and on their surface, many hydrophobic amino acids. The presence on their surface of hydrophobic amino acids facilitates their packaging into very complex supramolecular structures.
In this regard, it should be noted that their polypeptide chains form long filaments or sheets, where in most cases **only one type of secondary structure, that repeats itself, is found**. In vertebrates, these proteins provide external protection, support and shape; in fact, thanks to their structural properties, they ensure flexibility and/or strength.
Some fibrous proteins, such as α-keratins, are only partially hydrolyzed in the intestine. Here are some examples.

1. **Fibroin:** It is produced by spiders and insects. An example is that produced by the silkworm, *Bombyx mori*.
2. **Collagen:** The term “collagen” indicates not a single protein but a family of structurally related proteins (at least 29 different types), which constitute the main protein component of connective tissue, and more generally, the extracellular scaffolding of multicellular organisms.
3. In vertebrates, they represent about 25-30% of all proteins.
They are found in different tissues and organs, such as tendons and the organic matrix of bone, where they are present in very high percentages, but also in cartilage and in the cornea , In the different tissues, they form different structures, each capable of satisfying a particular need. For example, in the cornea, the molecules are arranged in an almost crystalline array, so that they are virtually transparent, while in the skin they form fibers not very intertwined and directed in all directions, which ensure the tensile strength of the skin itself.
Note: the different types of collagen have low nutritional value as deficient in several amino

acids (in fact, they contain no tryptophan and low amount of the other essential amino acids). The gelatin used in food preparation is a derivative of collagen.

4. **α-Keratins:** They constitute almost the entire dry weight of nails, claws, beak, hooves, horns, hair, wool, and a large part of the outer layer of the skin. The different stiffness and flexibility of these structures is a consequence of the number of disulfide bonds that contribute, together with other binding forces, to stabilize the protein structure. And this is the reason why wool keratins, which have a low number of disulfide bonds, are flexible, soft and extensible, unlike claw and beak keratins that are rich in disulfide bonds.
5. **Elastin:** This protein provides elasticity to the skin and blood vessels, a consequence of its random coiled structure that differs from the structures of the α-keratins and collagens.

Globular proteins

Most of the proteins belong to this class. They have a compact and more or less spherical structure, more complex than fibrous proteins. In this regard, motifs, domains, tertiary and quaternary structures are found, in addition to the secondary structures. They are generally soluble in water but can also be found inserted into biological membranes (transmembrane proteins), thus in a hydrophobic environment.

Unlike fibrous proteins, that have structural and mechanical functions, they act as:

1. enzymes
2. hormones
3. membrane transporters and receptors
4. transporters of triglycerides, fatty acids and oxygen in the blood
5. immunoglobulins or antibodies
6. grain and legume storage proteins

Examples of globular proteins are myoglobin, hemoglobin, and cytochrome c. At the intestinal level, most of the globular proteins of animal origin are hydrolyzed almost entirely to amino acids.

Protein classification based on biological functions

The multitude of functions that proteins perform is the consequence of both the folding of the polypeptide chain, therefore of their three-dimensional structure, and the presence of many different functional groups in the amino acid side chains, such as thiols, alcohols, thioethers, carboxamides, carboxylic acids and different basic groups.

From the functional point of view, they may be divided into several groups.

1. Enzymes (biochemical catalysts): In living organisms, almost all reactions are catalyzed by specific proteins called enzymes. They have a high catalytic power, increasing the rate of the reaction in which they are involved at least by factor 10^6. Therefore, life as we know could not exist without their "facilitating action". Almost all known enzymes, and in the human body they are thousand, are proteins (except some catalytic RNA molecules called ribozymes, that is, ribonucleic acid enzymes).

2. Transport proteins: Many small molecules, organic and inorganic, are transported in the bloodstream and extracellular fluids, across the cell membranes, and inside the cells from one compartment to another, by specific proteins. Examples are: hemoglobin, that carries oxygen from the alveolar blood vessels to tissue capillaries; transferrin, which carries iron in the blood; membrane carriers; fatty acid binding proteins (FABP), that is, the proteins involved in the intracellular transport of fatty acids; Proteins of plasma lipoproteins, macromolecular complexes of proteins and lipids responsible for the transport of triglycerides, which are otherwise insoluble in water; albumin, that carries free fatty acids, bilirubin, thyroid hormones, and certain medications such as aspirin and penicillin, in the blood.

Many of these proteins also play a protective role, since the bound molecules, such as fatty acids, may be harmful for the organism when present in free form.

3. Storage proteins: Examples are: ferritin that stores iron intracellularly in a non-toxic form; milk caseins, that act as a reserve of amino acids for the milk; egg yolk phosvitin, that contains high amounts of phosphorus; prolamins and glutelins, the storage proteins of cereals.

Protein classification based on solubility

The different globular proteins can be classified based on their **solubility in different solvents**, such as water, salt and alcohol.

7.16.2 Properties

A protein is a biological macro molecule composed of one or more chain of amino acids linked by peptide bonds. In general, we speak of protein when the string contains more than 50 amino acids. For smaller sizes, we speak of peptide and polypeptide, but more often they are simply "small protein". The Dutch chemist Gerhard Mulder (1802-1880) discovered proteins. The word protein comes from the Greek “protos” which means first, essential. This probably refers to the fact that proteins are essential to life and they often constitute the majority share (60%) of the dry weight of cells. Another theory that would make reference protein as the adjective protean, with the Greek God Proteus who could change shape at will. The proteins indeed adopt many forms and provide multiple functions. But, this was not discovered until much later, during the twentieth century.

Solubility in Water

1. The relationship of proteins with water is complex. The secondary structure of proteins depends largely on the interaction of peptide bonds with water through hydrogen bonds.
2. Hydrogen bonds are also formed between protein (alpha and beta structures) and water. The protein-rich static balls are more soluble than the helical structures.

3. At the tertiary structure, water causes the orientation of the chains and hydrophilic radicals to the outside of the molecule, while the hydrophobic chains and radicals tend to react with each other within the molecule (cf. hydrophobic effect).
4. The solubility of proteins in an aqueous solution containing salts depends on two opposing effects on the one hand related to electrostatic interactions ("salting in") and other hydrophobic interactions (salting out).

Denaturation

A protein is denatured when its specific three-dimensional conformation is changed by breaking some bonds without breaking its primary structure. It may be, for example, the disruption of helix areas. The denaturation may be reversible or irreversible. It causes a total or partial loss of biological activity. This is an important property of protein.

There are a number of Denaturing agents as follows.

(a) Physical agents: Heat, radiation, pH

(b) Chemical agents: Urea solution which forms new hydrogen bonds in the protein, organic solvents, detergents.

Biological role

Proteins have a pivotal role in the stabilization of many structures. Examples are α-keratins, collagen and elastin. The same cytoskeletal system, the scaffold of the cell, is made of proteins. They generate movement. They are responsible, among others, for the contraction of the muscle fibers (of which myosin is the main component); the propulsion of spermatozoa and microorganisms with flagella; the separation of chromosomes during mitosis. They are involved in nerve transmission. An example is the receptor for acetylcholine at synapses.

1. They control development and differentiation: Some proteins are involved in the regulation of gene expression. An example is the nerve growth factor (NGF), discovered by Rita Levi-Montalcini, that plays a leading role in the formation of neural networks.

2. Hormones: Many hormones are proteins. They are regulatory molecules involved in the control of many cellular functions, from metabolism to reproduction. Examples are insulin, glucagon, and thyroid-stimulating hormone (TSH).

3. Protection against harmful agents: The antibodies or immunoglobulins are glycoproteins that recognize antigens expressed on the surface of viruses, bacteria and other infectious agents. Interferon, fibrinogen, and factors of blood coagulation are other members of this group.

Storage of energy: Proteins, and in particular the amino acids that constitute them, act as energy storage, second in size only to the adipose tissue, that in particular conditions, such as prolonged fasting, may become essential for survival. . However, their reduction of more than 30% leads to a decrease of the contraction capacity of respiratory muscle, immune function, and organ function that are not compatible with life. Therefore, proteins are an extremely valuable fuel.

7.17 ENZYMOLOGY

The cell may be like a minute laboratory which is capable of carrying out various processes like synthesis and breakdown of various substances. These processes carried out by an **enzyme** at normal body temperature, low ionic strength, low pressure and narrow range of pH. The study of enzyme is called **enzymology.** Enzymes are **biocatalyst**, macromolecules of biological origin, which speeds up a chemical reaction but remain, unchanged itself at the end, so that it can be used again and again. They have extraordinary catalytic power, often far greater than that of synthetic or inorganic catalysts.

French chemist **Anselme Payen** was first to discover an enzyme, diastase in 1833. But biological catalysis was recognized and described in the 1850s by **Louis Pasteur**. He revealed that the 'living intact' yeast cells were responsible for fermentation of sugar in to alcohol and used the term 'ferments' for such catalysts. Then in 1897 **Edward Buchner** discovered that yeast extracts could ferment sugar to alcohol, because of this work he is credited for the discovery of enzyme and **Frederick W. Kuhne** coined the word enzymes (en= in, zyme= yeast). **James B. Summer** (1926) isolated enzyme urease for the first time in crystalline form from Jack bean, *Canavalia ensiformis* at the Cornell University. Sumner found that urease crystals completely made up of proteins and he postulated that all enzymes are proteins. But Sumner's conclusion was widely accepted, only after **John Northrop** crystallized pepsin, trypsin and other digestive enzymes and found them also to be proteins. On the basis of all these findings, he determined the proteinaceous nature of enzymes. For such a pioneer and innovative work, Sumner and Northrop share the Nobel Prize in 1947.

7.17.1 Nomenclature

The name of enzymes according to the older system has often been haphazard and confusing. Therefore, a systematic approach of nomenclature of the enzymes has been recommended by the **Commission on enzymes of the International Union of Biochemistry** (1961), according to which the various enzymes are designated by code numbers consisting of four digits (*E.C. number* or *Enzyme Commission number*).

Characteristic features of International Union of Biochemistry (IUB) system
• Enzymes are divided into six major classes, each with 4-13 subclasses. • The name enzyme have two parts: the first part indicates the name of substrate and second part indicates the type of reaction ending with suffix –ase. • Each enzyme has a systematic four-digit code number (EC number).

The first digit of **E.C. number** indicates the major class, the second digit indicates the sub-class, and the third digit indicates its sub-sub class, while the fourth digit denotes the systematic specific name of the enzymes, the first part of which indicates the name of the substrate and the second part the nature of the reaction. For example- the code no. 1.1.1.1. stands for the enzyme *alcohol dehydrogenase* where -

1. Stands for **oxidoreductase**.

1.1. Stands for enzyme which utilizes substrate as – **CHOH group**.

1.1.1. Stands for those enzymes which utilize **NAD** as an acceptor.

7.17.2 -Major classes:

1. **Oxidoreductase** – catalyze oxidation-reduction reaction (transfer of electrons or protons).
2. **Transferases** – catalyze reaction which involves transfer of functional groups from one molecule to another molecule.
3. **Hydrolases** – catalyze breaking of one molecule in to two molecules by adding water molecule (transfer of functional group to water).
4. **Lyases** – catalyze reactions in which either a double bond is established due to the removal of a group or a group is added to the double bond.
5. **Isomerases** – catalyze isomerisation reactions (transfer of functional group within the molecule).
6. **Ligases** – also called as synthetases, catalyze those reactions in which linking of two molecules are coupled with the breakdown of pyrophosphate bond of ATP or similar triphosphate.

7.17.3 Characteristics of enzymes

Enzymes possess the following major characteristics -

1. Enzymes are proteinaceous in nature.
2. Enzymes remain unchanged qualitatively and quantitatively at the end of reaction they catalyze.
3. Enzymes increase the rate of reactions but they do not initiate reaction.
4. Enzymes do not alter the chemical equilibrium point of a chemical reaction.
5. Enzymes are required in very minute quantity in respect to substrate.
6. Enzymes are very efficient; an average enzyme undergoes about 1000 reactions per second.
7. Enzymes are highly specific, that is an enzyme will generally catalyze only a single reaction.
8. Enzymes lower the activation energy of the reactions they catalyze.
9. Enzymes form complexes with substrates.
10. Enzymes activity is affected by pH, temperature, substrate and enzyme concentration.

7.17.4 - Properties of Enzymes

1. Catalytic Property - Enzymes are capable of catalyzing biochemical reactions. They transform large number of substrate into products without undergoing any change themselves. Catalytic power of enzyme is measured in terms of "**turn over number**". Turn over number is the number of substrate molecules converted into product per unit time, when the enzyme is fully saturated with substrates.

2. Colloidal Nature - Enzymes are partly or totally proteins hence they are colloidal in nature. They have high molecular weight and low diffusion rate and form colloidal system in water.

3. Reversibility - In most of the cases the reactions catalyzed by the enzymes are reversible depending upon the requirements of the cell.

4. Specificity - Enzymes are highly specific in action with few exceptions, i.e. particular enzyme can catalyze only a particular type of reaction.

5. Heat Sensitivity (Thermostability) - The enzymes are proteinaceous in nature, hence they are thermo labile. They work in narrow range of temperature (20^{o}C – 40^{o}C). Beyond 45^{o}C enzymes get **denatured** i.e. they looses their activity due to change in 3-D structure of protein and their properties are not restored even after giving suitable temperature.

6. pH Sensitivity - Each enzyme acts best at certain pH. Most of the enzymes act in neutral pH. Any increase or decrease in medium pH leads to slow down or inhibition of enzymatic activity.

7.17.5 Concept of enzyme

In this topic, you have learnt about enzymes, its types and mechanisms. The basic requirement for life is, the organism must be able to catalyze chemical reactions efficiently and selectively. Most chemical reactions require an initial input of energy to get started. This initial investment of energy is known as the **energy of activation**. A catalyst is a substance that lowers the activation energy required for a reaction. Enzymes are biological catalyst that speeds up reaction without being consumed by the reaction. Thus enzymes are typically effective in very small amounts.

The enzyme catalyzed reactions differ from ordinary chemical reactions in following ways-

1. The rates of enzyme catalysed reactions are very high, approximately 10^6 to 10^{12} times greater than ordinary unanalyzed reactions.
2. Enzymes are highly specific, to recognize the minute and specific differences in substrate and product molecules, even able to discriminate between mirror images of the same molecule.
3. Enzyme reactions typically occur at normal body temperature, low ionic strength, low pressure and narrow range of pH near neutrality.
4. Enzymes activities have regulatory control on metabolic reactions of living organism in balance by various activators and inhibitors.

The molecule on which an enzyme acts is known as its **substrate**. The substrate binds with the enzymes active site by weak interactions. The **active site** is the location on the enzyme where the catalysis of chemical reaction and product formation takes place. Thus, active site both confines the substrate molecule and orients it in correct manner.

7.17.6 - Mode of Action

1. Lock and Key model: This model was proposed by a German chemist **Emil Fischer** in 1898. According to this model, lock is analogous to enzymes and its socket (in which key fits) is analogous to active site, while key is analogous to substrate. It is believed that the enzyme and substrate both have strictly complementary structures which during complex formation fit to each other like a specific key in a particular lock. This model explains enzyme specificity in which a substantially rigid active site is likened to a 'lock' and the substrate to a 'key' that fits the lock. The enzyme substrate complex dissociates only after the conversion of substrate into products and the enzyme becomes free and available for further reactions.

2. Induced Fit model: This model was proposed by **Daniel Koshland** in 1966. According to this model, the enzyme and substrate do not have strictly complementary structures but the enzyme has flexible active site structure which is changed according to substrate configuration (Figure – 11.5). This model explains enzyme specificity in which a flexible active site is induced, by a substrate, to change its conformation to an orientation properly fitting the substrate's geometry. Enzyme-substrate complex brings about conformational change in active site, in such a fashion so that catalytic group lies opposite the substrate bonds to be broken. ES binding forces exert strain to form products.

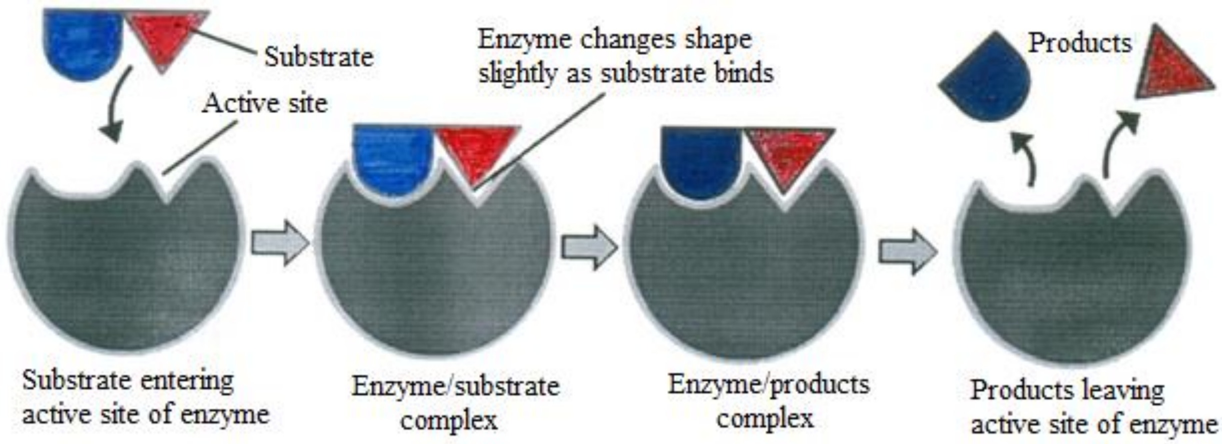


Fig.7.15: Diagram of induced fit model, representing the flexible nature of the active site of the enzymes

7.17.7 - Enzyme Inhibitors

A variety of small molecules exists which can reduce the rate of an enzyme controlled reaction. They are called enzyme inhibitors. Enzyme inhibitors may be reversible or irreversible. Irreversible inhibitors bound covalently to the enzymes and destroy the functional group of the active site. Most of the irreversible inhibitors are toxic substances or antibiotics and are tightly bound to the enzymes.

Reversible inhibitors can dissociate from the enzyme because they bind non-covalently to the enzymes. Reversible inhibitors are of three different types; competitive, non-competitive and mixed type.

1. Competitive inhibition: Competitive inhibition is the simplest and most common form of reversible inhibition. It binds to the enzyme at active site with an affinity similar to or stronger than that of the substrate. The competitive inhibitor forms an enzyme-inhibitor complex [EI] that is equivalent to enzyme-substrate complex [ES]. Competitive inhibition is usually based on the fact that the structure of the inhibitor resembles that of the substrate; hence the strong affinity of the inhibitor for the active site. The effect of competitive inhibitor is reversed by increasing the substrate concentrations. At high substrate concentration, all the active sites are filled with the substrates and reaction velocity similar to the value observed without an inhibitor. The diagnostic property of this type of inhibition is that V_{max} is same and K_m increases, but such inhibitors does not affect the 'turn over number'.

2. Non-competitive inhibition: In noncompetitive inhibition, the inhibitor does not compete with the substrate for binding to the active site. Instead, it may bind to another site and obstruct the substrate's access to the active site because binding alters the 3-D structure of the enzyme, or it may bind to the enzyme–substrate complex and thus alter catalysis. Noncompetitive inhibition is not reversed by increasing substrate concentration. The diagnostic property of this type of inhibition is that Km is unaffected, whereas Vmax decreases in the presence of increasing amounts of inhibitor.

3. Mixed inhibition: Mixed inhibition is characterized by effects on both Vmax (which decreases) and Km (which increases). Mixed inhibition is very common and results from the formation of a complex consisting of the enzyme, the substrate, and the inhibitor that does not break down to products.

7.18 SUMMARY

In this unit you have learnt about the mechanisms of photosynthesis occuring in plants. So let us sum it up.

1. Photosynthesis is the chemical change which happens in the leaves of green plants. It is the first step towards making food - not just for plants but ultimately every animal on the planet.
2. All green parts of a plant have chloroplasts.
3. However, the leaves are the major site of photosynthesis for most plants. There are about half a million chloroplasts per square millimeter of leaf surface.
4. The color of a leaf comes from chlorophyll, the green pigment in the chloroplasts. Chlorophyll plays an important role in the absorption of light energy during photosynthesis.
5. Powered by light, the green parts of plants produce organic compounds and O_2 from CO_2 and H_2O.
6. The equation describing the process of photosynthesis is:
   a. $6CO_2 + 12H_2O + \text{light energy} \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$
   b. $C_6H_{12}O_6$ is glucose.
7. Water appears on both sides of the equation because 12 molecules of water are consumed, and 6 molecules are newly formed during photosynthesis.
8. We can simplify the equation by showing only the net consumption of water:
   a. $6CO_2 + 6H_2O + \text{light energy} \longrightarrow C_6H_{12}O_6 + 6O_2$

9. Photosynthesis is two processes, each with multiple stages.
10. The light reactions (photo) convert solar energy to chemical energy.
11. The Calvin cycle (synthesis) uses energy from the light reactions to incorporate CO_2 from the atmosphere into sugar.
12. In the light reactions, light energy absorbed by chlorophyll in the thylakoids drives the transfer of electrons and hydrogen from water to NADP+ (nicotinamide adenine dinucleotide phosphate), forming NADPH.
    a. NADPH, an electron acceptor, provides reducing power via energized electrons to the Calvin cycle.
    b. Water is split in the process, and O_2 is released as a by-product.
13. The light reaction also generates ATP using chemiosmosis, in a process called photophosphorylation.
14. Thus light energy is initially converted to chemical energy in the form of two compounds: NADPH and ATP.
15. The cycle begins with the incorporation of CO_2 into organic molecules, a process known as carbon fixation.
16. The fixed carbon is reduced with electrons provided by NADPH.
17. ATP from the light reactions also powers parts of the Calvin cycle.
18. Thus, it is the Calvin cycle that makes sugar, but only with the help of ATP and NADPH from the light reactions.
19. The metabolic steps of the Calvin cycle are sometimes referred to as the light-independent reactions, because none of the steps requires light directly.
20. Nevertheless, the Calvin cycle in most plants occurs during daylight, because that is when the light reactions can provide the NADPH and ATP the Calvin cycle requires.
21. While the light reactions occur at the thylakoids, the Calvin cycle occurs in the stroma.
22. There are two types of photosystems in the thylakoid membrane.
    a. Photosystem I (PS I) has a reaction center chlorophyll a that has an absorption peak at 700 nm.
    b. Photosystem II (PS II) has a reaction center chlorophyll a that has an absorption peak at 680 nm.
    c. The differences between these reaction centers (and their absorption spectra) lie not in the chlorophyll molecules, but in the proteins associated with each reaction center.
    d. These two photosystems work together to use light energy to generate ATP and NADPH.
23. During the light reactions, there are two possible routes for electron flow: cyclic and noncyclic.
24. Noncyclic electron flow, the predominant route, produces both ATP and NADPH.
25. Under certain conditions, photoexcited electrons from photosystem I, but not photosystem II, can take an alternative pathway, cyclic electron flow.
    a. Excited electrons cycle from their reaction center to a primary acceptor, along an electron transport chain, and return to the oxidized P700 chlorophyll.

  b. As electrons flow along the electron transport chain, they generate ATP by cyclic photophosphorylation.
  c. There is no production of NADPH and no release of oxygen.

26. Certain plant species have evolved alternate modes of carbon fixation to minimize photorespiration.
27. C_4 plants first fix CO_2 in a four-carbon compound.
  a. Several thousand plants, including sugarcane and corn, use this pathway.
28. A unique leaf anatomy is correlated with the mechanism of C_4 photosynthesis.
29. In C_4 plants, there are two distinct types of photosynthetic cells: bundle-sheath cells and mesophyll cells.
  a. Bundle-sheath cells are arranged into tightly packed sheaths around the veins of the leaf.
  b. Mesophyll cells are more loosely arranged cells located between the bundle sheath and the leaf surface.
30. C_4 photosynthesis minimizes photorespiration and enhances sugar production.
31. A second strategy to minimize photorespiration is found in succulent plants, cacti, pineapples, and several other plant families.
  a. These plants are known as CAM plants for crassulacean acid metabolism.
  b. They open their stomata during the night and close them during the day. Temperatures are typically lower at night, and humidity is higher.
  c. During the night, these plants fix CO_2 into a variety of organic acids in mesophyll cells.
  d. During the day, the light reactions supply ATP and NADPH to the Calvin cycle, and CO_2 is released from the organic acids.
32. Both C_4 and CAM plants add CO_2 into organic intermediates before it enters the Calvin cycle.
33. Carbohydrates are complex biochemical structures and have vital functions in the human body. In the body, carbohydrates are broken down into simple sugars and absorbed into the bloodstream. Carbohydrates come from a wide array of foods - bread, beans, milk, popcorn, potatoes, cookies, spaghetti, corn, and cherry pie.
34. Lipids are a large and diverse group of naturally occurring organic compounds. They show differential solubility in nonpolar organic solvents (e.g. ether, chloroform, acetone & benzene) and are generally insoluble in water. Fatty acids are the hydrocarbon chain with one carboxylic acid (-COOH) group. Fatty acids are main components of many lipids, constitutes an even number of carbon atoms (generally 12 to 24). Lipids include fats, waxes, sterols, fat-soluble vitamins (such as vitamins A, D, E, and K), monoglycerides, diglycerides, triglycerides, phospholipids, and others. Lipids that contain a functional group ester are hydrolysable in water. These include neutral fats, waxes, phospholipids, and glycolipids. Nonhydrolyzable lipids include steroids and fat-soluble vitamins (e.g. A, D, E, and K). Fats and oils are made of triacylglycerols or triglycerides which are composed of glycerol (1, 2, 3-trihydroxypropane) and 3 fatty acids to form a triester. Complete hydrolysis of triacylglycerols yields three fatty acids and a glycerol molecule. The plasma membrane is

made up of proteins and lipids. The main biological functions of lipids include storing energy, functioning as structural components of cell membranes and acting assignaling molecules.

35. Protein, highly complex substance that is present in all living organisms. Proteins are of great nutritional value and are directly involved in the chemical processes essential for life. The importance of proteins was recognized by chemists in the early 19th century, including Swedish chemist Jöns Jacob Berzelius, who in 1838 coined the term protein, a word derived from the Greek proteios, meaning “holding first place.” Proteins are species-specific; that is, the proteins of one species differ from those of another species. They are also organ-specific; for instance, within a single organism, muscle proteins differ from those of the brain and liver.
36. An enzyme is a protein that catalyzes a chemical reaction by lowering the activation energy. They are not changed or used in reactions, so only a small amount of enzyme is needed. They are highly specific for their substrate and functionally depend on their three-dimensional structure, which is sensitive to temperature and pH. The actual catalytic process takes place at the active site via formation of enzyme-substrate complex. The ‘lock and key’ hypothesis provide reason for the specificity of the active site, according to which the shape of the active site is complementary to that of the substrate. While ‘induced-fit’ hypothesis revealed that the enzyme-substrate interaction may cause a conformational change in the active site. Enzymes adjust their shape to the substrate so there is a better fit. Some enzymes require cofactors for their catalytic activity. Such enzymes use inorganic molecule or complex organic molecules, which become bound during the reaction to activate the enzyme. The velocity of the enzyme-catalyzed reactions depends on the substrate concentration. The characteristic curve described in this reaction is a hyperbola that reaches a maximum velocity (V_{max}) when all the enzyme active sites are saturated. Enzymes activity is regulated by reversible and irreversible inhibition in the cells. Irreversible inhibitors typically form covalent bonds while reversible inhibitors form non-covalent bonds with the enzyme and may have competitive, non-competitive and mixed effect. The competitive inhibitors compete for the enzyme’s active site, while noncompetitive inhibitor binds to the allosteric site of the enzyme.

7.19 GLOSSARY

ADP- Adenosine diphosphate, product of the Calvin cycle that is used in the light-dependent reactions.

ATP- Adenosine triphosphate. ATP is a major energy molecule in cells. ATP and NADPH are products of the light-dependent reactions in plants. ATP is used in reduction and regeneration of RuBP.

Autotrophs- Photosynthetic organisms which convert light energy into the chemical energy they need to develop, grow, and reproduce.

Calvin cycle- Set of chemical reactions of photosynthesis that does not necessarily require light. The Calvin cycle takes place in the stroma of the chloroplast. It involves the fixing of carbon dioxide into glucose using NADPH and ATP.

Carbon fixation- ATP and NADPH are used to fix CO_2 into carbohydrates. Carbon fixation takes place in the chloroplast stroma.

Chemical equation of photosynthesis - $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$

Chlorophyll- Primary pigment used in photosynthesis. Plants contain two main forms of chlorophyll: a & b. Chlorophyll has a hydrocarbon tail that anchors it to an integral protein in the thylakoid membrane of the chloroplast. Chlorophyll is the source of the green color of plants and certain other autotrophs.

Chloroplast - Organelle in a plant cell where photosynthesis occurs.

G3P - Isomer of PGA formed during the Calvin cycle

Glucose ($C_6H_{12}O_6$) - Sugar that is the product of photosynthesis. Glucose is formed from 2 PGAL's.

Granum - Stack of thylakoids (plural: grana)

Light - Electromagnetic radiation; the shorter the wavelength the greater amount of energy. Light supplies the energy for the light reactions of photosynthesis.

Light harvesting complexes (photosystems complexes) - Multi-protein unit in the thylakoid membrane that absorbed light to serve as energy for reactions

Light reactions (light dependent reactions) - Chemical reactions requiring electromagnetic energy (light) that occur in the thylakoid membrane of the chloroplast to convert light energy into chemical forms ATP and NAPDH.

Lumen - Region within the thylakoid membrane where water is split to obtain oxygen. The oxygen diffuses out of the cell, while the protons remain inside to build positive electrical charge inside the thylakoid.

Mesophyll cell - A type of plant cell located between the upper and lower epidermis that is the site for photosynthesis

NADPH – A high-energy electron carrier used in reduction

Oxidation - The loss of electrons

Oxygen (O_2) - Gas that is a product of the light-dependent reactions

Palisade mesophyll - Area of the mesophyll cell without many air spaces

PGAL - Isomer of PGA formed during the Calvin cycle.

Photosynthesis - The process by which organisms convert light energy into chemical energy (glucose).

Photosystem – A cluster of chlorophyll and other molecules in a thylakoid that harvest the energy of light for photosynthesis

Pigment - Colored molecule. A pigment absorbs specific wavelengths of light. Chlorophyll absorbs blue and red light and reflects green light, so it appears green.

Reduction - The gain of electrons
Rubisco - An enzyme that bonds carbon dioxide with RuBP
Thylakoid - Disc-shaped portion of chloroplast, found in stacks
Cholesterol- A type of fatty acid that is vital for the normal functioning of the body.
Glycogen- A multi-branched polysaccharide of glucose that serves as a form of energy storage in humans, animals, and fungi.
Haworth projection- A Haworth projection is a common way of writing a structural formula to represent the cyclic structure of monosaccharides with a simple three-dimensional perspective.
Hormones- A chemical substance produced in the body that controls and regulates the activity of certain cells or organs.eg insulin.
Active site: The region on the surface of an enzyme where catalytic activity occurs.

7.20 SELF ASSESSMENT QUESTIONS

7.20.1 Objective type questions:

1. During light phase of photosynthesis ______ is oxidized and ______ is reduced.
(a) CO_2 and Water (b) Water and CO_2
(c) Water and NADP (d) $NADPH_2$ and CO_2

2. During dark phase of photosynthesis ______ is oxidized and ______ is reduced.
(a) CO_2 and Water (b) Water and CO_2
(c) Water and NADP (d) $NADPH_2$ and CO_2

3. The visible product of photosynthesis is ______
(a) glucose (b) cellulose
(c) starch (d) fructose

4. Glycolytic reversal is a part of ______
(a) aerobic respiration (b) anaerobic respiration
(c) light phase of photosynthesis (d) dark phase of photosynthesis

5. The source of CO_2 during calvin cycle in C_4 plant is
(a) Malic acid (b) OAA
(c) PEP (d) RuDP

6. Absorption spectrum of chlorophyll is maximum in _____ light.
(a) red (b) blue
(c) yellow (d) blue-violet

7. The oxygen molecule in glucose formed during photosynthesis comes from

(a) Water (b) Organic acids
(c) CO_2 (d) atmosphere

8. Light reaction of photosynthesis results in formation of
(a) O_2 (b) NADPH +H+
(c) ATP (d) All of these

9. The chemical formula of carbohydrate is
(a) $(CH_2O)n$ (b) $(CH_2O)2n$
(c) (CHO)n (d) CnH_2nO

10. Which of the following statements about enzymes is true-
(a) Enzymes are biocatalyst.
(b) Enzymes are mostly proteins.
(c) Enzymes speed up reactions by lowering activation energy.
(d) All of the above

7.20.2 True/ False

1. Photosynthesis takes place only in high intensity of light.
2. During photosynthesis the reaction when PGA is converted into PGAL, is called reduction.
3. During light reaction CO_2 reacts with H_2.
4. In C_3 pathway, the first stable compound is PGA.
5. The source of oxygen evolved during photosynthesis is H_2O.
6. In C_4 plants, synthesis of glucose occurs in bundle sheath cells.
7. In cyclic and non-cyclic photophosphorylation, the first acceptor of electron are ferridoxin and plastoquinone respectively.
8. Release of oxygen occurs during both cyclic and non-cyclic photophosphorylation.
9. During Photosynthesis water is oxidized and CO_2 is reduced.
10. Calvin was given Nobel prize in 1961 for his discovery of photolysis of water.

7.20.1 Answer Keys: 1- (c), 2-(d), 3-(c), 4-(d), 5-(a), 6-(b), 7-(c), 8-(d), 9-(a), 10- (d).
7.20.2 Answer Keys: 1-False, 2-True, 3-False, 4-True, 5-True, 6-True, 7-True, 8-False, 9-True, 10-False.

7.21 REFERENCES

- Bryant DA, Frigaard NU (Nov 2006). "Prokaryotic photosynthesis and phototrophy illuminated". Trends in Microbiology. **14** (11): 488–96. doi:10.1016/j.tim.2006.09.001. PMID 16997562.

- Plants: Diversity and Evolution, page 14, Martin Ingrouille, Bill Eddie
- Campbell NA, Williamson B, Heyden RJ (2006). Biology Exploring Life. Upper Saddle River, NJ: Pearson Prentice Hall. ISBN 0-13-250882-6.
- Smith, Alison (2010). Plant biology. New York, NY: Garland Science. p. 5. ISBN 0815340257.
- Whitmarsh J, Govindjee (1999). "The photosynthetic process". In Singhal GS, Renger G, Sopory SK, Irrgang KD, Govindjee. Concepts in photobiology: photosynthesis and photomorphogenesis. Boston: Kluwer Academic Publishers. pp. 11–51. ISBN 0-7923-5519-9.
- "Photosynthesis". McGraw-Hill Encyclopedia of Science & Technology. **13**. New York: McGraw-Hill. 2007. ISBN 0-07-144143-3.
- Whitmarsh J, Govindjee (1999). "Chapter 2: The Basic Photosynthetic Process". In Singhal GS, Renger G, Sopory SK, Irrgang KD, Govindjee. Concepts in Photobiology: Photosynthesis and Photomorphogenesis. Boston: Kluwer Academic Publishers. p. 13. ISBN 978-0-7923-5519-9.
- A.L. Lehninger, D.L. Nelson and M.M. Cox (1993), *Principles of Biochemistry* (second edition), CBS Publishers & Distributors, Delhi.
- D.B. Northrop (1999), Rethinking of enzyme activity. *Adv. Enzymol.* 73: 25.
- D.J. Taylor, N.P.O. Green and G.W. Stout (editor: R. Scoper) (1997), *Biological Science* (third edition), Cambridge University Press.
- G.G. Hammes (2008), How do enzymes really work? *J. Biol. Chem.* 283: 22337.
- H. Suzuki (2015), *How enzyme work : from structure to function*, CRC Press.
- J.B. Losos, K.A. Mason and S.R. Singer (2010), *Biology* (eighth edition), Tata McGraw Hill Education Private Limited, New Delhi.
- J.M. Berg, J.L. Tymoczko, L. Stryer and G.J. Gatto (2012), *Biochemistry* (seventh edition), W.H. Freeman & Company, New York.
- T. Palmer (1985), *Understanding enzymes*, Ellis Horwood, London.
- T.R. Cech (1987), The chemistry of self-splicing RNA and RNA enzymes. *Science* 236: 1532.
- W.M. Becker, L.J. Kleinsmith and J. Hardin (2005), *The world of the cell* (sixth edition), Pearson Benjamin Cummings Publication, San Francisco.
- W.W. Cleland (1977), Determining the chemical mechanisms of enzyme-catalysed reactions by kinetic studies. *Adv. Enzymol.* 45: 273.

7.22 SUGESSTED READINGS

- Photosynthesis.(Sixth Edition). David O Hall Krishna Rao. Cambridge University Press.
- Plant Physiology and Biochemistry. H.S Srivastava. Rastogi Publications.Meerut.
- Botany for Degree students. B.P Pandey. S.Chand Publications.
- Fundamentals of plant physiology. V.K Jain. S.Chand Publications.

- A textbook of botany. V.Singh, P.C Pande and D.K Jain. (2008)
- Textbook of Plant Physiology and Biochemistry. Mohit Verma and Pooja Gupta.
- A textbook of Plant Physiology, Biochemistry and Biotechnology. Dr. S.K Verma and Mohit Verma.
- Lehninger Principles of Biochemistry 5th Edition by David L. Nelson (Author), Michael M. Cox (Author)
- Biochemistry by Berg JM,Tymoczko JL, and Stryer L, published by W.H. Freeman and Company.
- Biochemistry, 4th Edition by Donald Voet, Judith G. Voet
- Principles and Techniques of Biochemistry and Molecular Biology by Wilson, K. & Walker, J.
- http://en.wikipedia.org/wiki/enzyme
- T. Palmer (1985), *Understanding enzymes*, Ellis Horwood, London.

7.23 TERMINAL QUESTIONS

7.23.1 Long Answer Questions:

1. What is photosynthesis? Describe the role of light and chlorophyll in photosynthesis.
2. Comment on major chemical events occuring in the dark reactions of photosynthesis.
3. Write a concise account of photophosphorylation.
4. Give an account on Calvin cycle.
5. What are carbohydrates?
6. What are Monosaccharides, Oligosaccharides, and Polysaccharides?
7. Write short note on biological function of carbohydrates?
8. Describe the structures and functions of any two homo and hetropolysaccharides?
9. What are lipids?
10. What are enzymes?

UNIT 8- GENETICS AND PLANT BREEDING

Contents:

8.1 OBJECTIVES

After reading this unit students will be able-

- To understand the genetic inheritance
- To understand about Mendel's experiment and laws of inheritance, and an insight into Mendelian or Classical Genetics.
- to Define linkage and crossing over
- to know aim and ojectives of plant breeding
- to learn techniques of plant breeding

8.2 INTRODUCTION

All living organism reproduce and reproduction results in the formation of offspring of their same kind. However, the resulting offspring need not always resemble to the parent. Several characteristics may differ among individual belonging to the same species. These differences are known as *variations.* The mechanism of transmission of characters from parents to offspring, resemblance as well as differences, is termed as *heredity*. The scientific study of heredity, variation and the environmental factor accountable for these variations is known as *genetics.*

The father of genetics is Gregor Mendel (1822-1844), a late 19th-century scientist and Austrian monk and a teacher in Augustinian Monastery at Brunn (in Czeckoslovakia, now called Brno). Mendel studied 'trait inheritance', patterns in the way traits (character) were handed down from parents to offspring. He discovered that individual traits are inherited as discrete *factors* which retain their physical identity in a hybrid. Later on these factors were called *genes*. The term 'gene' was given by Danish botanist Wilhelm Johannsen in 1990. Traits studied by Mendel were clear and discrete. Such discrete traits are known as *Mendelian characters.*

Every chromosome in a cell contains many genes and each gene is located at a particular site or *locus* in the chromosome. Chromosomes that carry same set of genes in the same sequence are called *homologous* for example human body cell contains 23 pairs of homologous chromosome.

Alleles are the alternative forms of a gene, which code for different versions of a particular inherited character. We can also define it as genes occupying corresponding positions on homologous chromosomes and controlling the same characteristic (e.g. height of plant) but producing different effects (tall or short). A dominant allele hides the expression of a recessive allele and it is represented by the uppercase letter. A recessive allele is the allele that expresses its effect only in homozygous state and in heterozygous condition its expression is masked by dominant allele. It is represented by lowercase letter.

Homozygous and Heterozygous

Each diploid parent has two allels for a trait- they may be:

1. Homozygous, when they possess two identical alleles for a trait.

Homozygous dominant (TT)

Homozygous recessive (tt)

2. Heterozygous, when they possess one of each allele for a particular trait (Tt).

Genotype and Phenotype

These terms are used in genetics to distinguish the physical appearance from the genetic constitution. Genotype is defined as the genetic constitution of an individual for any particular character or trait, usually expressed by symbol e.g. tt, Tt or TT etc. The physical appearance of an individual for any particular trait is defined as the phenotype. Phenotype of an individual is dependent on its genetic constitution.

8.3 MENDEL’S EXPERIMENT AND LAWS OF INHERITANCE

The laws of inheritance were derived by Gregor Mendel, a nineteenth-century Austrian monk conducting hybridization experiments in garden peas (*Pisum sativum*). Between 1856 and 1863, he cultivated and tested some 5,000 pea plants. He published the results of his experiment in ‘Annual Proceedings of Natural History Society of Brunn’.From these experiments, he induced two generalizations which later known as *Mendel's Principles of Heredity* or *Mendelian inheritance*.

Mendel's Laws

Mendel discovered that, when he crossed pure red white flower and purple flower pea plants (the parental or P generation), the result was not a blend. Rather than being a mix of the two, the offspring (known as the F_1 generation) was purple-flowered. When Mendel self-fertilized the F_1 generation pea plants, he obtained a purple flower to white flower ratio in the F_2 generation of 3 to 1. The results of this cross are tabulated in the Punnett square below.

He then conceived the idea of heredity units, which he called "factors". Mendel found that there are alternative forms of factors - now called genes - that account for variations in inherited characteristics. For example, the gene for flower colour in pea plants exists in two forms, one for purple and the other for white. The alternative forms are now called alleles.

Mendel also hypothesized that allele pairs separate randomly, or segregate, from each other during the production of gametes: egg and sperm. Because allele pairs separate during gamete production, a sperm or egg carries only one allele for each inherited trait. When sperm and egg unite at fertilization, each contributes its allele, restoring the paired condition in the offspring. This is called the **Law of Segregation**. Mendel also found that each pair of alleles segregates independently of the other pairs of alleles during gamete formation. This is known as the **Law of Independent Assortment**.

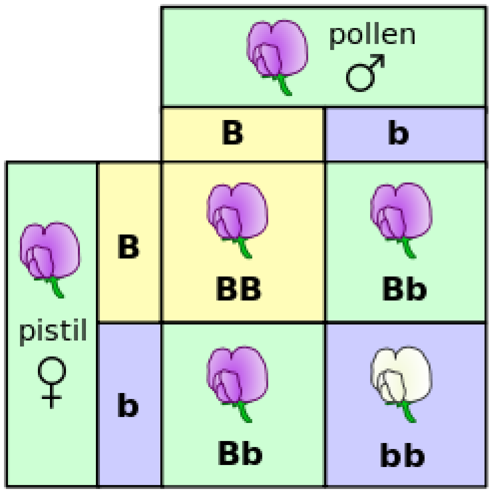


Fig.8.1 A Punnett square for one of Mendel's pea plant experiments

The genotype of an individual is made up of the many alleles it possesses. An individual's physical appearance, or phenotype, is determined by its alleles as well as by its environment. The presence of an allele does not mean that the trait will be expressed in the individual that possesses it. If the two alleles of an inherited pair differ (the heterozygous condition), then one determines the organism's appearance and is called the dominant allele; the other has no noticeable effect on the organism's appearance and is called the recessive allele. Thus, in the example above dominant purple flower allele will hide the phenotypic effects of the recessive white flower allele. This is known as the **Law of Dominance** but it is not a transmission law, dominance has to do with the expression of the genotype and not its transmission.

In the pea plant example above, the capital "P" represents the dominant allele for purple flowers and lowercase "p" represents the recessive allele for white flowers. Both parental plants were true-breeding, and one parental variety had two alleles for purple flowers (*PP*) while the other had two alleles for white flowers (*pp*). As a result of fertilization, the F_1 hybrids each inherited one allele for purple flowers and one for white. All the F_1 hybrids (*Pp*) had purple flowers, because the dominant *P* allele has its full effect in the heterozygote, while the recessive *p* allele has no effect on flower colour. For the F_2 plants, the ratio of plants with purple flowers to those with white flowers (3:1) is called the phenotypic ratio. The genotypic ratio, as seen in the Punnett square, is 1 *PP*: 2 *Pp* : 1 *pp*.

8.3.1-Principle of Segregation

Mendel followed the inheritance of 7 pea traits. Dominant traits, like round peas, appeared in the first-generation hybrids (F1), whereas recessive traits, like wrinkled peas, were masked. However, recessive traits reappeared in the second generation (F2). Each individual carries a pair of factors for each trait, and they separate from each other during fertilization. This is the basis of Mendel's principle of segregation.

On the basis of monohybrid cross (a cross involving only one trait), Mendel formulated the law of Segregation, this law states that every individual contains a pair of alleles for each particular trait which segregate or separate during cell division (assuming diploidy) for any particular trait and that each parent passes a randomly selected copy (allele) to its offspring. The offspring then receives its own pair of alleles of the gene for that trait by inheriting sets of homologous chromosomes from the parent organisms. Interactions between alleles at a single locus are termed dominance and these influence how the offspring expresses that trait (e.g. the colour and height of a plant, or the color of an animal's fur). At the time of formation of gametes each member of the pair of genes separate from each other so that each gamete carries only one factor (gene) i.e. gametes are always pure (law of purity of gametes).

Definition: The Law of Segregation states that the two alleles for a heritable character segregate (separate from each other) during gamete formation and end up in different gametes.

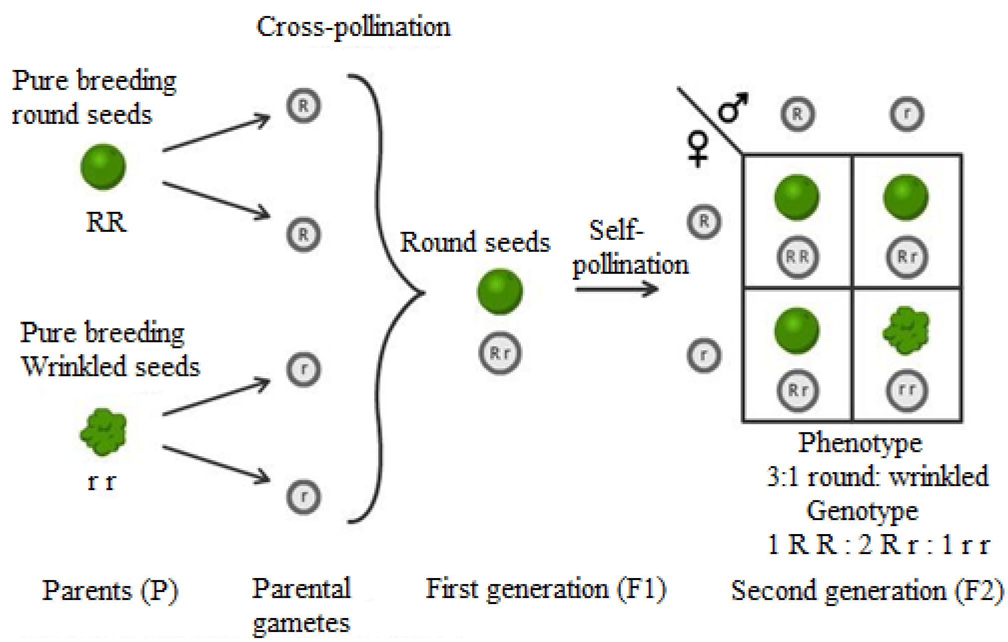


Fig. 8.2 Dominant and recessive phenotypes

8.3.2-Principle of Independent Assortment

The law in short stated that: In the inheritance of more than one pair of traits in a cross simultaneously, the factor responsible for each pair of traits are distributed to the gametes. The Law of Independent Assortment, also known as "Inheritance Law", states that separate genes for separate traits are passed independently of one another from parents to offspring. That is, the biological selection of a particular gene in the gene pair for one trait to be passed to the offspring has nothing to do with the selection of the gene for any other trait. More precisely, the law states that alleles of different genes assort independently of one another during gamete formation. While Mendel's experiments with mixing one trait always resulted in a 3:1 ratio (Fig. 1) between dominant and recessive phenotypes, his experiments with mixing two traits (dihybrid cross) showed 9:3:3:1 ratios (Fig. 5.3). But the 9:3:3:1 table shows that each of the two genes is independently inherited with a 3:1 phenotypic ratio. Mendel concluded that different traits are inherited independently of each other, so that there is no relation, for example, between a pea seed shape (round or wrinkled) and seed colour (yellow or green). This is actually only true for genes that are not linked to each other.

A dihybrid cross shows Mendel's Law of Independent Assortment

In a dihybrid cross we are looking at the inheritance of two traits at the same time. Instead of looking at flower colour, we are going to look at two traits that affect the pea. Peas can either be round or wrinkled, and they can either be yellow or green. Round is dominant to wrinkled, so use **R** to represent round. Wrinkled is recessive and is represented by **r**. Always use the same letter so that you know you are specifying the same character. The dominant colour in peas is yellow, so we will use **Y** for yellow and **y** for green. Before Mendel could perform a dihybrid cross, he had to create a line that was true-breeding for both traits, so in this case the line with peas that always had round shape and were always yellow were genotype **RRYY**, and the line with peas that were always wrinkled and green were **rryy**. What do you expect in the F1 generation when you cross these two true-breeding lines? That is straight forward because the only gametes that the round yellow plants can make will have the **RY** genotype, and the only gametes that the wrinkled green plants can make will have the **ry** genotype. Therefore, all of their offspring will be heterozygous. The phenotype of the F1 will be all round and yellow because those are the dominant traits.

Then, Mendel allowed these F1 plants to self-fertilize. This is where things got a bit tricky. These heterozygotes can make four different types of gametes. Do you know what they are? Write them down before you look at Figure 2 below. The law of segregation applies to each character. In addition, the two characters are independent when gametes are formed. So, the heterozygous plants can make four types of gametes, with all of the possible allelic combinations. There are gametes that are parental, **RY** and **ry**. They are called *parental* because they were also made by the parents in the P1 generation. However, you also find unique combinations of gametes, **Ry** and **rY**. These are *recombinant* gametes. Because each heterozygous individual can make four types of gametes, this results in a Punnett square with sixteen possible combinations.

Independent assortment occurs in eukaryotic organisms during meiotic metaphase I, and produces a gamete with a mixture of the organism's chromosomes. The physical basis of the independent assortment of chromosomes is the random orientation of each bivalent chromosome along the metaphase plate with respect to the other bivalent chromosomes. Along with crossing over, independent assortment increases genetic diversity by producing novel genetic combinations.

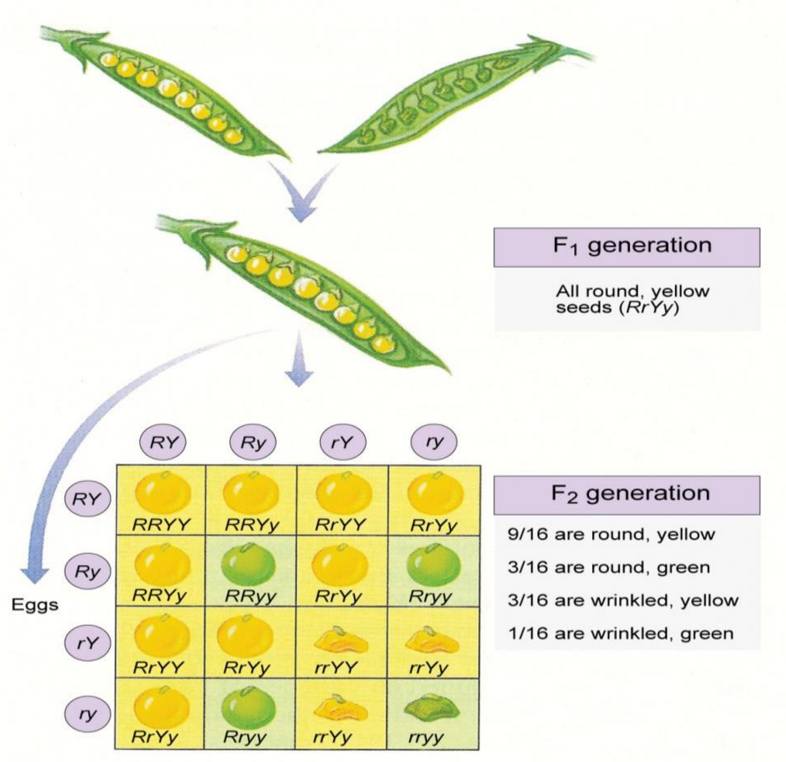


Fig.8.3 The results of a dihybrid Cross

Of the 46 chromosomes in a normal diploid human cell, half are maternally derived (from the mother's egg) and half are paternally derived (from the father's sperm). This occurs as sexual reproduction involves the fusion of two haploid gametes (the egg and sperm) to produce a new organism having the full complement of chromosomes. During gametogenesis the production of new gametes by an adult-the normal complement of 46 chromosomes needs to be halved to 23 to ensure that the resulting haploid gamete can join with another gamete to produce a diploid organism. An error in the number of chromosomes, such as those caused by a diploid gamete joining with a haploid gamete, is termed aneuploidy.

In independent assortment, the chromosomes that result are randomly sorted from all possible combinations of maternal and paternal chromosomes. Because gametes end up with a random mix instead of a pre-defined "set" from either parent, gametes are therefore considered assorted independently. As such, the gamete can end up with any combination of paternal or maternal chromosomes. Any of the possible combinations of gametes formed from maternal and paternal chromosomes will occur with equal frequency. For human gametes, with 23 pairs of chromosomes, the number of possibilities is 2^{23} or 8,388,608 possible combinations. The gametes will normally end up with 23 chromosomes, but the origin of any particular one will be randomly selected from paternal or maternal chromosomes. This contributes to the genetic variability of progeny.

8.3.3-Incomplete Dominance

Mendel's Law of Dominance states that recessive alleles will always be masked by dominant alleles. Therefore, a cross between a homozygous dominant and a homozygous recessive will always express the dominant phenotype, while still having a heterozygous genotype. Law of Dominance can be explained easily with the help of a mono hybrid cross experiment:- In a cross between two organisms pure for any pair (or pairs) of contrasting traits (characters), the character that appears in the F1 generation is called "dominant" and the one which is suppressed (not expressed) is called "recessive." Each character is controlled by a pair of dissimilar factors. Only one of the characters expresses. The one which expresses in the F1 generation is called Dominant. It is important to note however, that the law of dominance is significant and true but is not universally applicable.

According to the latest revisions, only two of these rules are considered to be laws. The third one is considered as a basic principle but not a genetic law of Mendel. Mendel explained inheritance in terms of discrete factors 'genes', that are passed along from generation to generation according to the rules of probability. Mendel's laws are valid for all sexually reproducing organisms, including garden peas and human beings. However, Mendel's laws stop short of explaining some patterns of genetic inheritance. For most sexually reproducing organisms, cases where Mendel's laws can strictly account for the patterns of inheritance are relatively rare. Often, the inheritance patterns are more complex.

Non-Mendelian Inheritance

The F_1 offspring of Mendel's pea crosses always looked like one of the two parental varieties. In this situation of "complete dominance," the dominant allele had the same phenotypic effect whether present in one or two copies. But for some characteristics, the F_1 hybrids have an appearance *in between* the phenotypes of the two parental varieties. A cross between two four o'clock (*Mirabilis jalapa*) plants shows this common exception to Mendel's principles. Some alleles are neither dominant nor recessive. The F_1 generation produced by a cross between red-flowered (RR) and white flowered (WW) *Mirabilis jalapa* plants consists of pink-colored flowers (RW). Which allele is dominant in this case? Neither one. This third phenotype results from flowers of the heterozygous having less red pigment than the red homozygous. Such conditions in which one allele is not completely dominant or semidominant or partial dominant over another are called **incomplete dominance**. In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes.

A similar situation arises from **codominance**, in which alleles that lack dominant and recessive relationships, and are both observed phenotypically to same degree. For example, in certain varieties of chicken, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens have a color described as "erminette," speckled with black and white feathers. Unlike the blending of red and white colours in heterozygous four o'clocks, black and white colours appear separately in chickens. Many human genes, including one for a protein that controls cholesterol levels in the blood, show codominance, too. People with the heterozygous form of this gene produce two different forms of the protein, each with a different effect on cholesterol levels.

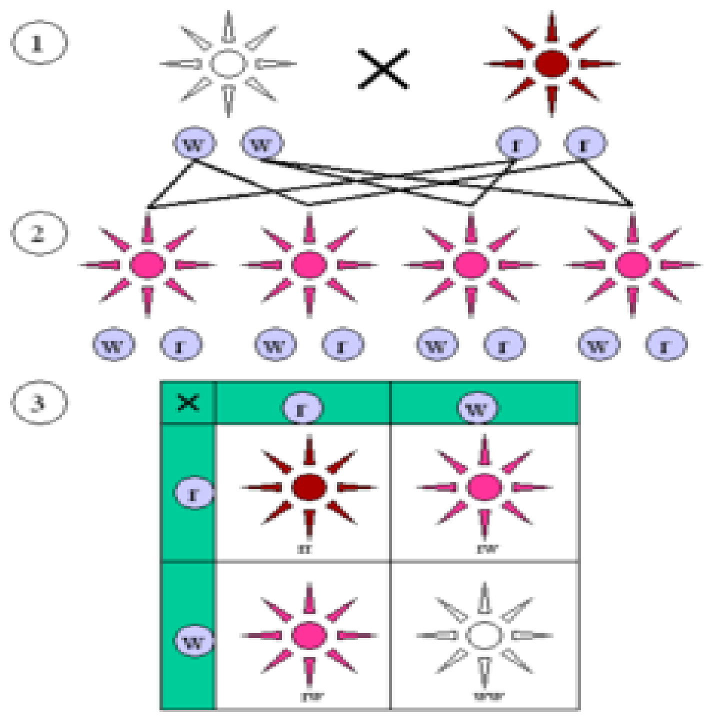


Fig.8.4. In four o'clock plants, the alleles for red and white flowers show incomplete dominance. As seen in the F_1 generation, heterozygous (*wr*) plants have "pink" flowers—a mix of "red" (rr) and "white" (ww) coloring. The F_2 generation shows a 1:2:1 ratio of red: pink:white

In Mendelian inheritance, genes have only two alleles, such as *A* and *a*. In nature, such genes exist in several different forms and are therefore said to have **multiple alleles**. A gene with more than two alleles is said to have multiple alleles. An individual, of course, usually has only two copies of each gene, but many different alleles are often found within a population. One of the best-known examples is coat color in rabbits. A rabbit's coat color is determined by a single gene that has at least four different alleles. The four known alleles display a pattern of simple dominance that can produce four coat colors. Many other genes have multiple alleles, including the human genes for ABO blood type.

Furthermore, many traits are produced by the interaction of several genes. Traits controlled by two or more genes are said to be **polygenic traits**. *Polygenic* means "many genes." For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Polygenic traits often show a wide range of phenotypes. The variety of skin color in humans comes about partly because more than four different genes probably control this trait.

8.4 LINKAGE AND CROSSING OVER

Mendel's Second Law, or the law of the independent assortment, is valid for genes located in different chromosomes. These genes segregate independently during meiosis. However, Mendel's Second Law is not valid for phenotypical features conditioned by genes located in the same chromosome (genes under linkage), since these genes, known as linked genes, do not separate during meiosis (except for the phenomenon of crossing over). The fruit fly, or drosophila, has been suitable for studying genetics because it presents many distinct traits but only has four chromosomes (one sex chromosome and three autosomes).

Genetic linkage is the tendency of alleles that are located close together on a chromosome to be inherited together during meiosis. Genes whose loci are nearer to each other are less likely to be separated onto different chromatids during chromosomal crossover, and are therefore said to be genetically *linked*. In other words, the nearer two genes are on a chromosome, the lower is the chance of a swap occurring between them, and the more likely they are to be inherited together.

Significance of linkage

(i) Linkage plays an important role in determining the nature and scope of hybridization and selection programmes.

(ii) Linkage reduces the chances of recombination of genes and thus helps to hold parental characteristics together. It thus helps organism to maintain its parental, racial and other characters. For this reason plant and animal breeders find it difficult to combine various characters.

8.4.1-Complete Linkage

The genes located on the same chromosome do not separate and are inherited together over the generations due to the absence of crossing over. Complete linkage allows the combination of parental traits to be inherited as such. It is rare but has been reported in male Drosophila and some other heterogametic organisms.

Example 1:

A red eyed normal winged (wild type) pure breeding female Drosophila is crossed to homozygous recessive purple eyed and vestigial winged male. The progeny or F_1 generation individuals are heterozygous red eyed and normal winged. When F_1 males are test crossed to homozygous recessive female (purple eyed and vestigial winged), only two types of individuals are produced— red eyed normal winged and purple eye vestigial winged in the ratio of 1 : 1 (parental phenotypes only). Similarly during inbreeding of F_1 individuals, recombinant types are absent. In practice, this 1: 1 test ratio is never achieved because total linkage is rare.

Example 2:

In Drosophila, genes of grey body and long wings are dominant over black body and vestigial (short) wings. If pure breeding grey bodied long winged Drosophila (GL/ GL) flies are crossed with black bodied vestigial winged flies (gl/gl), the F_2 shows a 3 : 1 ratio of parental phenotypes (3 grey body long winged and one black body vestigial winged).

This is explained by assuming that genes of body colour and wing length are found on the same chromosome and are completely linked.

8.4.2-Incomplete Linkage

Genes present in the same chromosome have a tendency to separate due to crossing over and hence produce recombinant progeny besides the parental type. The number of recombinant individuals is usually less than the number expected in independent assortment. In independent assortment all the four types (two parental types and two recombinant types) are each 25%. In case of linkage, each of the two parental types is more than 25% while each of the recombinant types is less than 25%.

Example 1:

A red eyed normal winged or wild type dominant homozygous female Drosophila is crossed to homozygous recessive purple eyed and vestigial winged male. The progeny or F_1 individuals are heterozygous red eyed and normal winged. F_1 female flies are test crossed with homozygous recessive males. It does not yield the ratio of 1: 1: 1: 1. Instead the ratio comes out to be 9: 1: 1: 8. This shows that the two genes did not segregate independently of each other. The data obtained and reported is as follows:

Phenotype	Progeny	Observed	Expected if Complete Linkage	Expected if Independent Assortment
Parental Types				
	(a) Red eyed, normal winged	1339	1420	710
	(b) Purple eyed vestigial winged	1195	1420	710
Recombinant Types				
	(a) Red eyed, vestigial winged	152	Zero	710
	(b) Purple eyed, normal winged	152	Zero	710

Only 9.3% recombinant types were observed which is quite different from 50% recombinants in case of independent assortment. This shows that in the oocytes of the F_1 generation only some of the chromatids undergo cross-over while the majority is preserved intact. This produces 90.7% parental types in the progeny.

Example 2:

In Sweet Pea (*Lathyrus odoratus*) blue flower colour (B) is dominant over red flower colour (b) while the trait of long pollen (L) is dominant over round pollen (l). A Sweet Pea plant heterozygous for both blue flower colour and long pollen (BbLl) was crossed with double recessive red flowered plant with round pollen (bbll). It is similar to test cross. In case the genes of the two traits are unlinked, the progeny should have four phenotypes (Blue Long, Blue Round, Red Long, and Red Round) in the ratio of 1: 1: 1: 1 (25% each). In case the two genes are completely linked the progeny should have both the parental types (Blue Long and Red Round) in the ratio of 1: 1(50% each). Recombinants should not appear. However, in the above cross Bateson and Punnett (1906) found both parental and recombinant types but with different frequencies in the ratio of 7: 1: 1: 7. (7 + 7 Parental and 1 + 1 recombinant types).

Phenotype	**Progeny**	**Observed frequency**	**Expected frequency if complete linkage**	**Expected fre-quency if Independent assortment**
Parental Types	(i) Blue Long	43.7%	50%	25%
Recombinant Types	(ii) Red Round	43.7%	50%	25%
	(a) Blue Round	6.3%	0%	25%
	(b) Red Long	6.3%	0%	25%

Only 12.6% recombinant types were observed against the expected percentage of 50% in case of independent assortment. Therefore, the genes are linked but undergo recombination due to crossing over in some of the cases.

8.4.3-Linkage Group

A linkage group is a linearly arranged group of linked genes which are normally inherited together except for crossing over.

It corresponds to a chromosome which bears a linear sequence of genes linked and inherited together. Because the two homologous chromosomes possess either similar or allelic genes on the same loci, they constitute the same linkage group. Therefore, the number of linkage groups present in an individual corresponds to number of chromosomes in its one genome (all the chromosomes if haploid or homologous pairs if diploid). It is known as principle of limitation of linkage groups.

Fruit-fly *Drosophila melanogaster* has four linkage groups (4 pairs of chromosomes), human beings 23 linkage groups (23 pairs of chromosomes), Pea seven linkage groups (7 pairs of chromosomes), *Neurospora* 7 linkage groups (7 chromosomes), Mucor 2 linkage groups (2 chromosomes), *Escherichia coli* one linkage group (one pro-chromosome or nucleoid) while Maize has 10 linkage groups (10 pairs of chromosomes).

The size of the linkage group depends upon the size of chromosome. The smaller chromosome will naturally have smaller linkage group while a longer one has longer linkage group. This is subject to the amount of heterochromatin present in the chromosome. Thus Y-chromosome of man possesses 231 genes while human chromosome 1 has 2969 genes.

8.5 CROSSING OVER

Ever know a large family with many children, all of whom are indistinguishable from each other? Unless they are all identical twins, you have not encountered such a family. Non-twin siblings typically have a range of physical differences, from subtle distinctions in features to looking unrelated. Even though they inherited equal chromosomes from the same two parents, the combination of genes is diversified due to crossing over.

Crossing over is the exchange of genes between two chromosomes, resulting in non-identical chromatids that comprise the genetic material of gametes (sperm and eggs). This process results in the millions of sperm or eggs that are produced by an organism, each being different from one another. In other words, every single sperm or egg cell in your body is completely unique.

Think of it like two traders meeting to exchange their goods, resulting in both leaving with a more diverse collection of wares than they had before. Thanks to this process, living things have high diversity within populations, allowing for better chances of adaptation to changing conditions and survival of the species.

Crossing over occurs during meiosis I and is the process where homologous chromosomes pair up with each other and exchange different segments of their genetic material to form recombinant chromosomes. It can also happen during mitotic division, which may result in loss of heterozygosity. Crossing over is essential for the normal segregation of chromosomes during meiosis. Crossing over also accounts for genetic variation, because due to the swapping of genetic material during crossing over, the chromatids held together by the centromere are no longer identical. So, when the chromosomes go on to meiosis II and separate, some of the daughter cells receive daughter chromosomes with recombined alleles. Due to this genetic recombination, the offspring have a different set of alleles and genes than their parents do.

Chromosomal crossover (or **crossing over**) is the exchange of genetic material between homologous chromosomes that results in recombinant chromosomes during sexual reproduction. It is one of the final phases of genetic recombination, which occurs in the *pachytene* stage of prophase I of meiosis during a process called synapsis. Synapsis begins before the synaptonemal complex develops and is not completed until near the end of prophase I. Crossover usually occurs when matching regions on matching chromosomes break and then reconnect to the other chromosome.

Chromatids

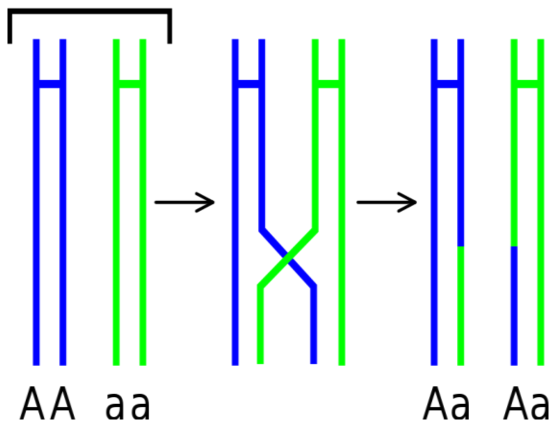


Fig. 8.5 Crossing over scheme

Crossing over was described, in theory, by Thomas Hunt Morgan. He relied on the discovery of the Belgian Professor Frans Alfons Janssens of the University of Leuven who described the phenomenon in 1909 and had called it "chiasmatype". The term *chiasma* is linked if not identical to chromosomal crossover. Morgan immediately saw the great importance of Janssens' cytological interpretation of chiasmata to the experimental results of his research on the heredity of *Drosophila*. The physical basis of crossing over was first demonstrated by Harriet Creighton and Barbara McClintock in 1931.

Types of Crossing Over

(i) Single crossing over

In this type of crossing over only one chiasma is formed all along the length of a chromosome pair. Gametes formed by this type of crossing over are called single cross over gametes.

(ii) Double crossing over

In this type two chiasmata are formed along the entire length of the chromosome leading to breakage and rejoin of chromatids at two points. The gametes produced are called double cross over gametes.

(iii) Multiple crossing over

In this type more than two chiasmata are formed and thus crossing over occurs at more than two points on the same chromosome pair. It is a rare phenomenon.

Significance of Crossing Over

1. Crossing over provides direct proof for the linear arrangement of genes,

2. Through crossing over segments of homologous chromosomes are interchanged and hence provide origin of new characters and genetic variations.

3. Crossing over has led to the construction of linkage map or genetic maps of chromosomes.

4. Linkage group and linear order of the genes help to reveal the mechanism of nature of genes.

5. Crossing over plays a very important role in the field of breeding to improve the varieties of plants and animals.

8.6 PLANT BREEDING

Plant breeding can be defined as a science as well as an art of improving the genetic makeup of plants in relation to their economic use. Recently plant breeding has been described as a technology of developing superior crop plants for various purposes.

"Plant breeding is the art and science of improving the heredity of plants for the benefit of mankind."

"Plant breeding deals with the genetic improvement of crop plants also known as science of crop improvement."

"Science of changing and improving the heredity of plants."

8.6.1 Aim of plant breeding

Plant breeding aims to improve the characteristics of plants so that they become more desirable agronomically and economically. The specific objectives may vary greatly depending on the crop under consideration.

Some Indian Plant Breeders and their contributions

T.S. Venkatraman - An eminent sugarcane breeder, he transferred thick stem and high sugar contents from tropical noble cane to North Indian Canes. This process is known as noblization of sugarcane.

B.P. Pal - An eminent Wheat breeder, developed superior disease resistant N.P. varieties of wheat.

M.S. Swaminathan - Responsible for green revolution in India, developed high yielding varieties of Wheat and Rice.

Pushkarnath - Famous potato breeder.

N.G.P. Rao - An eminent sorghum breeder.

K. Ramaiah - A renowned rice breeder.

Ram Dhan Singh - Famous wheat breeder.

D.S. Athwal - Famous pearlmillet breeder.

Bosisen - An eminent maize breeder.

Dharampal Singh - An eminent oil-seed breeder.

C.T. Patel - Famous cotton breeder who developed world's first cotton hybrid in 1970.

V. Santhanam - Famous cotton breeder.

Steps of Plant Breeding

The following are the major activities of plant breeding:
1. Collection of variation
2. Selection
3. Evaluation
4. Release
5. Multiplication
6. Distribution of the new variety

8.6.2 Objectives of plant breeding

1. Higher yield: The ultimate aim of plant breeding is to improve the yield of "*economic produce on economic part"***.** It may be grain yield, fodder yield, tuber yield, cane yield or oil yield depending upon the crop species.

2. Improved quality: The quality characters vary from crop to crop. e.g. grain size, colour, milling quality in barley, colour and size of fruits, nutritive and keeping quality in vegetables, protein content in pulses, oil content in oilseeds, fibre length, strength and fineness in cotton.

The production of improved quality of crop plants, like: rice, barley, wheat, etc.

3. Abiotic resistance: Crop plants also suffer from abiotic factors such as drought, soil salinity, extreme temperatures, heat, wind, cold and frost, breeder has to develop resistant varieties for such environmental conditions.

4. Biotic resistance: Crop plants are attacked by various diseases and insects, resulting in considerable yield losses. Genetic resistance is the cheapest and the best method of minimizing such losses.

5. Change in maturity Duration/ Earliness: Earliness is the most desirable character which has several advantages. It requires less crop management period, less insecticidal sprays, permits new crop rotations and often extends the crop area. Maturity has been reduced from 270 days to 170 days in cotton, from 270 days to 120 days in pigeon pea, from 360 days to 270 days in sugarcane.

6. Dormancy: In some crops, seeds germinate even before harvesting in the standing crop if there are rains at the time of maturity, e.g., green gram, black gram, barley and Pea, etc. A period of dormancy has to be introduced in these crops to check loss due to germination. In some other cases, however, it may be desirable to remove dormancy.

7. Desirable Agronomic Characteristics: It includes plant height, branching, tillering capacity, growth habit, erect or trailing habit etc., is often desirable. For.eg. dwarfness in cereals is generally associated with lodging resistance and better fertilizer response. Tallness, high tillering and profuse branching are desirable characters in fodder crops.

8. Elimination of Toxic Substances: It is essential to develop varieties free from toxic compounds in some crops to make them safe for human consumption. For example, removal of neurotoxin in khesari-lentil (*Lathyruys sativus*) which leads to paralysis of lower limbs, erucic acid from *Brassica* which is harmful for human health, and gossypol from the seed of cotton is necessary to make them fit for human consumption. Removal of such toxic substances would increase the nutritional value of these crops.

9. Photo and Thermo insensitivity: Development of varities insensitive to light and temperature helps in crossing the cultivation boundaries of crop plants. Photo and thermo-insensitive varities of wheat and rice has permitted their cultivation in new 7 areas. Rice is now cultivated in Punjab, while wheat is a major *rabi* crop in West Bengal.

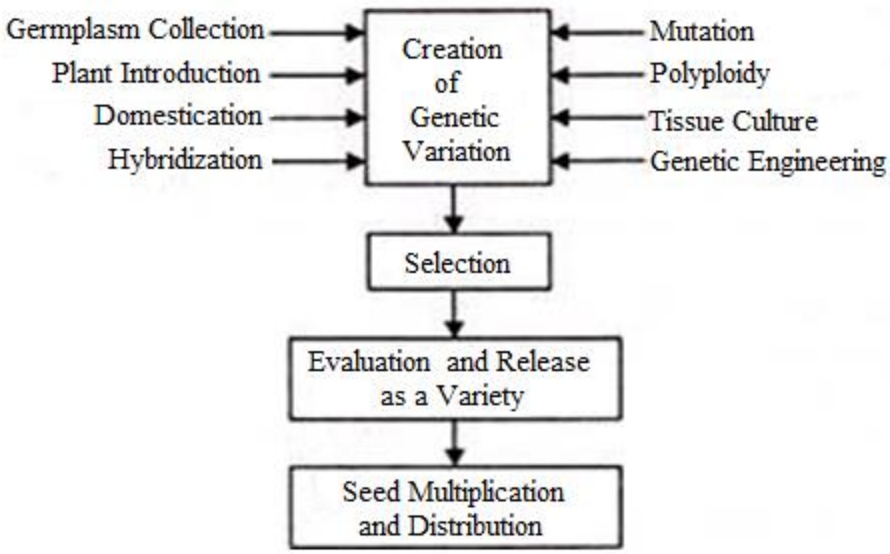
10. Wider adaptability: Adaptability refers to suitability of a variety for general cultivation over a wide range of environment conditions. Adaptability is an important objective in plant breeding because it helps in stabilizing the crop production over regions and seasons.

8.6.3 Basics techniques of plant breeding

The various methods of breeding used for crop improvement are as follows:-

1. Domestication
2. Plant introduction
3. Hybridization
4. Polyploidy breeding
5. Mutation breeding
6. Tissue culture technique
7. Genetic engineering

1. Domestication: Domestication is the process of growing plants and keeping animals under human care and management. This is the very first step aimed at increasing food production. Domestication of plants is an artificial selection process conducted by humans to produce plants that have more desirable traits than wild plants, and which renders them dependent on artificial environments for their continued existence. The domestication of wheat provides an example of how natural selection and mutation can play a key role in the process. A large number of agricultural, horticultural and medicinal plants have been domesticated by humans since the beginning of civilization. Crop plants include a long list of food, vegetables, oilseeds, pulses, fodders, fibre and sugar yielding crops.



2- Plant Introduction

(a) It is the process of introducing plants or germplasms either from a foreign country or introducing plants or germplasm from one region to other regions of the same country.

(b) Plant introduction is followed by *acclimatisation*, i.e., the adaptation of an individual plant or a population of plants, under the changed climate. It is an ancient method of crop improvement.

(c) Introduction of plants from a foreign country is called *intercontinental* plant introduction**. For example:**

(i) Groundnut has been introduced in India from Brazil,
(ii) Rubber has been introduced from South and Central America to India,
(iii) Mexican wheat varieties have been introduced from Mexico to India.

(d) Examples of introduced ornamental plants are innumerable, such as Jacaranda, Bougainvillea, Salvia, Cosmos, Dianthus, Antirrhinum etc.

(e) Introduction of plants from one state of a country to another state of the same country is called interstate plant introduction. For example, N.P. wheat varieties were introduced from Delhi to different states of India.

(f) Purposes of Plant Introduction
(i) For use in agriculture, forestry and industry.
(ii) For genetically improvement of economical crops.
(iii) For studying the origin, distribution, classification and evolution of the plants.

(g) Plant Introduction in India: Following agencies carry out plant introduction in India:
(i) Plant Introduction Division of IARI, New. Delhi,
(ii) Forest Research Institute, Dehradun.

(iii) Botanical Survey of India.
(iv) Some universities, gardens and agricultural departments also play an important role in introducing plants.

3. Hybridization

Hybridization may be defined as *"The mating or crossing of two plants or lines of dissimilar genotype."* The chief objective of hybridization is to create genetic variation. When two genotypically different plants are crossed, the genes from both the parents are brought together in F1 generation.

Segregation and recombination produce many new gene combinations in F2 and the later generations, i.e., segregating generations. The degree of variation produced in the segregating generations would, therefore, depend on the number of heterozygous genes in the F1. This will, in turn, depend upon the number of genes for which the two parents differ.

If the two parents are closely related, they are likely to differ for a few genes only. But if they are not related, or are only distantly related, they may differ for several, even a few hundred genes. However, it is most unlikely that the two parents will ever differ for all the genes. Therefore, when it is said that the F1 is 100 percent heterozygous, it has reference only to those genes for which two parents differ. The aim of hybridization may be transfer of one or few qualitative characters, improvement of one or more quantitative characters, or use of the F1 as a hybrid variety.

Technique of Hybridization: Before performing hybridisation, a plant breeder should have all the information about the time of flowering, the time when the anther and. stigma are ready for pollination, how long do the pollen grains remain viable, etc.

The actual technique consists of the following steps:

(i) The first step is the selection of parents from the available material possessing desired characters.

(ii) Second step is the selfing of plants to obtain homozygosity in desired characters. This step is not practiced in self pollinated crops because they are already homozygous.

(iii) Third step is emasculation. In this, the anthers are removed before they mature and have shed their pollens. Purpose of emasculation is to prevent self-pollination. It is not practiced in unisexual crops.

(iv) Bagging, tagging and labeling of males as well as females to be used in crosses, is done.

(v) Fifth step is the crossing, in which the pollen from bagged males are dusted on to the bagged female plant.

(vi) Lastly, seeds are collected from the crossed plants after maturity. Seeds are maintained separately and sown in the coming season to raise F generation.

Hybridization in Self-Pollinated Crops: Several methods, like pedigree method, bulk method and back-cross method are in practice.

(a) Pedigree Method: In this method, F1 hybrids possessing desirable characters are selected. The seeds from each plant are collected and grown separately to raise F2 generation. This process is repeated for a number of generations. Finally, the plants with desired characters are recommended for cultivation.

(b) Bulk Method: In this method, F1 hybrids rather than being grown separately are grown in bulk. Seeds, from F2 plants are also sown together and the process continued for 5-6 generations till homozygosity is obtained.

(c) Back-cross Method: F1 hybrids, in this method, are crossed by one of the above mentioned methods. This method is useful in the improvement of both self and cross-pollinated crops.

Hybridization in Cross-Pollinated Crops: Several methods like single cross, double cross, top cross and synthetic cross.

(a) Single Cross: It is a cross between two inbreeds. For example, A x B or C x D. The hybrids are distributed directly to farmers for cultivation.

(b) Double Cross: It is a cross between F1 hybrids of two different single crosses.

$A \times B$ → F_1 hybrid (AB)

$C \times D$ → F_1 hybrid (CD)

$AB \times CD$ → Double Cross hybrid (ABCD)

(c) Three-way Cross: It is a cross between F1 hybrid of a single cross and a third parent which is used as a male parent. For example,

Three Parents : A, B and C

$A \times B$

↓

$F_1 (A \times B) \times C$

↓

$[(A \times B) C]$

(d) Top Cross: It is a cross between an inbred and an open-pollinated variety.

Variety x Inbred

(e) Synthetic Cross: A number of inbreeds are crossed in order to combine different desirable characters into one variety.

4. Mutation Breeding: "Mutation is a sudden and heritable change in a character of an organism."

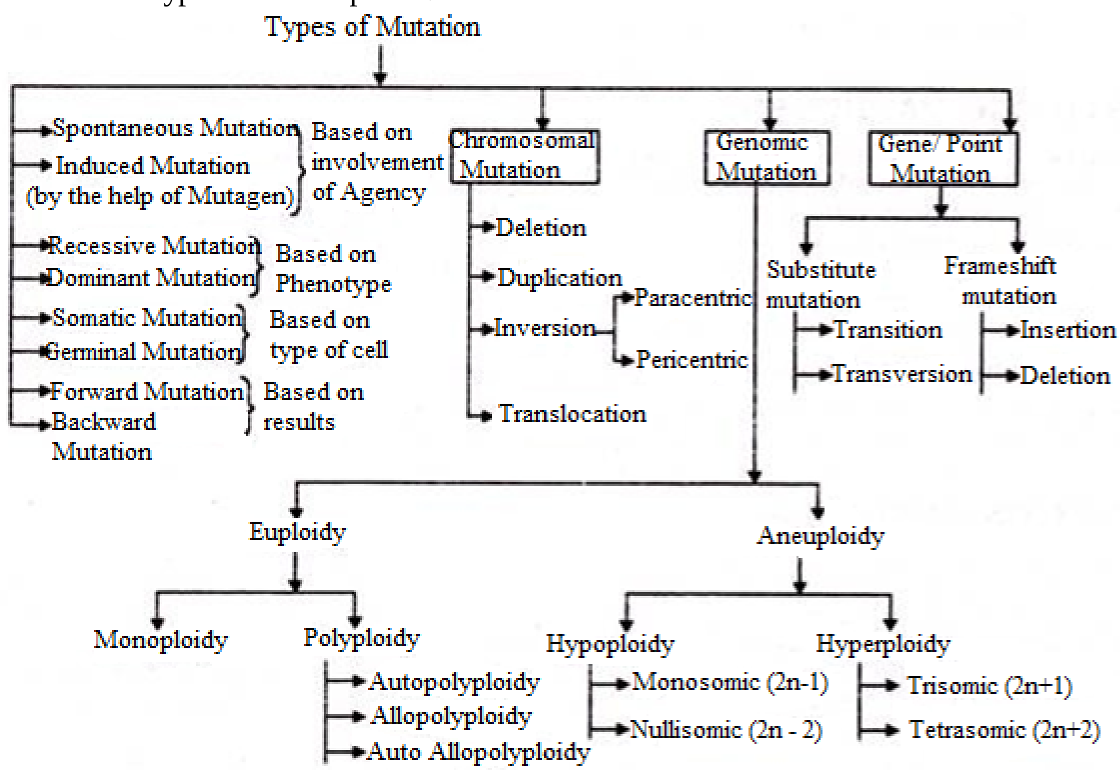
1. A number of crop varieties have been developed through mutation breeding.

2. The first commercial success with induced mutations was reported in 1934 with the release of a new tobacco cultivar 'Chlorina' through X-ray irradiation. The Indian dwarf wheat's which contain the dwarfing gene was from a Japanese cultivar 'Norin- 10', which itself was a mutant.

3. Many varieties of barley contain artificially mutated genes which contribute to reduction in height, increase in yield, insensitivity to day length and resistance to mildew diseases. Sharbati Sonara and Pusa Lerma are two amber grain colour mutants of wheat produced from the red grained Sonara 64 and Lerma Rojo 64A, respectively. A mutant gene that induces semi-dwarfing in rice has been produced by X-ray treatment. Induced mutations have also become recently important in developing parents useful in hybridization programmes. Forty-five rice cultivars have been developed by the year 1982, either by direct radiation or by crossing with induced mutants.

4. Many crop plants are propagated vegetatively even though they can bear seed. Potato, tapioca and sugarcane are classical examples of such crops. In these, genetic improvement is carried out using sexual reproduction but the maintenance of the improved varieties is by cloning. For examples, potatoes are multiplied by tubers, apples by cuttings, and strawberries by runners.

5. Spontaneous mutations in somatic cells of a vegetatively propagated plant are commonly referred to as SPORTS. Such desirable sports occurring in well- adapted, asexually reproducing plants may result in quick improvements such as the colour sports in many apple varieties and superior shrub types in coffee plants.



6. The characters improved through mutation breeding include flowering time, flower shape, fruit shape, changes in oil content, and protein quality.

7. Some of the important limitations of the use of mutation breeding for crop improvement are:

(i) Most induced mutations are undesirable and have no value to the breeder. Many induced mutations are lethal.

(ii) The mutation rate is extremely low and a very large number of plants must be screened to identify the few individuals that may have desirable mutations. It is equally difficult to grow such useful mutants and include them in breeding programmes.

(iii) The stability of a mutant must be thoroughly tested as some mutants have a tendency to revert.

(iv) Most induced mutations are recessive; these have to be in double dose to be expressed phenotypically.

(v) Unless mutations are induced in gametes—especially in pollen—they will not be easily incorporated into the breeding line.

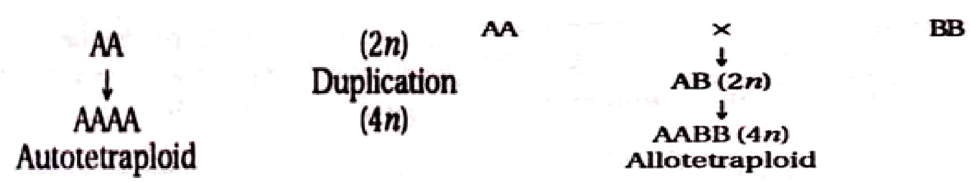
5. Polyploidy: Any organism in which the number of complete chromosome set is higher than the diploid number is called POLYPLOID and the phenomenon is known as polyploidy.

Types of Polyploids: There are two types of polyploids:

(i) **Euploids** are those forms in which the chromosome number has changed in such a way that an organism has an exact multiple of haploid number, such as triploids (3n), tetraploids (4n), pentaploids (5n), hexaploids (6n) and so on.

(ii**) Aneuploids or Heteroploids** are those forms in which the chromosome number has changed in such a way that an organism does not have an exact multiple of the haploid number. For example, 2n-1 (monosomics), 2n-2 (nullisomics), 2n+1 (trisomic), 2n+2 (tetrasomic), and likewise.

Euploidy has been used in plant breeding and improvement work. **Euploids are of two types: autopolyploids and allopolyploids.**



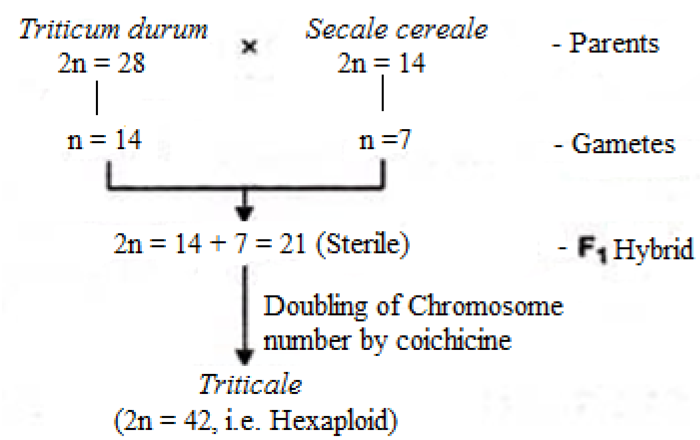
Induction of Polyploidy:

1. Polyploidy in plants can be induced by colchicine treatment.

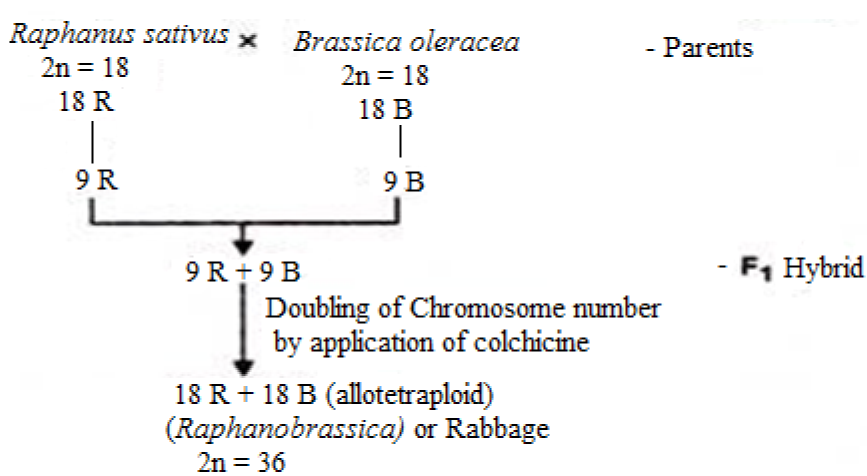
2. Colchicine is an alkaloid obtained from the corms of Colchicum autumnale (Liliaceae).

3.Colchicine inhibits the formation of the spindle in the dividing cells and hence chromosomes do not separate at anaphase. Thus, a restitution nucleus (it is a nucleus in which the chromosomes have divided but could not separate into two daughter nuclei) is formed. Effect of colchicine is temporary. As a cell recovers from treatment, a new spindle is formed and the restitution nucleus undergoes normal mitosis as a polyploidy cell.

Origin of Triticale: It is a man-made cereal, an allopolyploid between Triticum (wheat) and Secale (rye). The released varieties of Triticale are hexaploid (2n = 42) and have been synthesized by doubling the chromosome complements of sterile hybrids between *T. turgidum* (durum wheat, 2n = 28) and S. cereale (rye, 2n = 14).



Origin of a new genus, allotetraploid: *Raphano brassica* (2n = 36) from diploid parents, viz, *Raphanus sativus* (2n = 18) and *Brassica oleracia* (2n = 18).



6. Selection: Selection is one of the oldest methods for crop improvement. It can be natural or artificial and is possible only if there exist variation in the crop.

(A) Natural Selection acts as a sieve in favour of the well adapted strains and varieties. Natural selection is a rule in nature and has resulted in evolution, according to which only the fittest can survive. All local varieties of crops are the result of natural selection. Many differences between species and sub-species have arisen due to this selection pressure. It is always operating in nature and is one of the natural factors which create variations in the already existing varieties of crops.

(B) Artificial selection involves picking out of the plants having desired combination of characters from a mixed population where the individuals differ in characters. The various methods of artificial selection are:

a. Mass Selection: It is practiced in those plants which are cross-pollinated like *Zea*, *Brassica*. In this method, plants are selected based on the phenotypic expression from the mixed population of a crop. Then, the seeds of these selected plants are obtained. All the seeds are mixed in a single lot and therefore, the method is known as mass selection. The seeds so obtained are used for raising the next crop. Again from these plants, selection is made as earlier. This process is continued till the plants show uniformity in the desired characters.

b. Pure Line Selection: It is practiced in self-pollinated crops such as wheat, barley, rice, legumes. Here also the selection is made on the basis of phenotypic expression. But the seeds of one plant are not mixed with the seeds of another. So, it involves testing the progeny of single individual plant separately. Selection is again made from the progenies arising from the seeds of a single individual. This method of selection from a single individual is continued till a true breeding type is obtained.

c. Clonal Selection: This method is practiced in vegetatively propagated crops such as banana, potato, onion, citrus, etc. Clones are plants propagated vegetatively from a single individual. The genotypic constitution of plants propagated in this way is not likely to change.

Here in, superior clones are selected on the basis of their phenotypic characters. The selection is always between clones and never within a clone, as all the individuals of a clone have the same genetic constitution.

7. Plant Tissue Culture in Crop Improvement Programme: Lately, the tissue culture technology has played a very crucial role in crops improvement programme. Essentially the methodology of tissue culture consists of separating cells, tissues or organs of a plant and growing them aseptically in suitable containers on a nutrient medium under controlled conditions of temperature and light. The cultured parts (termed explants) require a source of energy (usually sucrose), salts, providing macro-and microelements, a few vitamins and generally the amino acid, glycine, in the nutrient medium. The amounts and the nature of salts used vary as there are several formulations developed by different scientists. Hormones and mixtures of substances such as yeast extract, coconut water, bean seed extract are included in the medium by some workers. An excised embryo or a shoot bud may develop into a whole plant. Pollinated ovaries have also been grown to mature fruits. Nevertheless, portions of organs or tissues generally give rise to an unorganized mass of cells called CALLUS.

In the early 1950's Skoog and Miller showed that shoot or roots can be induced in the callus (organogenesis) by an appropriate balance of amounts of cytokinin and auxin in the medium. We now know that the type of growth response in tissue cultures depends on the source of the explants, composition of the medium and conditions in the culture room.

The following are the benefits of tissue culture in crop improvement:

1. Rapid multiplication of desired plants (Micro propagation)

2. Multiplication of rare plants which reproduce through seeds with great difficulty.

3. To rescue embryos which fail to reach maturity.

4. Multiplication of sterile hybrids.

5. Production of virus-free plants.

6. Protoplast fusion or somatic hybridization.

7. To shortern the period for development of new varieties of plants.

8. To induce weedicides resistance in plants.

9. Induction and selection of mutants.

10. Somoclonal variation and DNA recombinant technology.

There are a few other uses of plant tissue culture such as production of artificial seeds, and germplasm storage and exchange.

8. Genetic Engineering and Biotechnology in Plant Breeding:

"Genetic engineering is a term used for the directed manipulation of genes, i. e. The transfer of genes between organisms or changes in the sequence of a gene."

The latest interest in crop improvement is not to involve whole genome (as in conventional plant breeding or in protoplast fusion). The objective of genetic engineering or recombinant DNA technology is to introduce one or more genes into an organism that normally does not possess them. This requires isolation of a fragment of DNA corresponding to a desirable character (or function), inserting it into a vector (such as the plasmid in a bacterium, *Agrobacterium tumifaciens*), and transferring it to a cell.

Genetic transformation is also possible through co-cultivation (incubating recipient protoplast with purified DNA), electroporation (by applying high electric potential for a few micro-seconds to change the porosity of protoplast to take up DNA) and by micro-injection of DNA into the cell by fine needles. Although the above account may sound simplistic and exciting, there are several obstacles in realizing the objectives.

Successful genetic engineering requires identification of the desired genes, their transfer to the cells of a target crop plant, their integration and expression. We know a good deal about genome organisation in a prokaryotic organism such as *E. Coli*. However, the genetic material of the eukaryotes is quite complex. Our present knowledge of the location and function of the specific genes in crop plants is so poor that genetic engineering is still very problematic. Each crop plant contains one to ten million genes. Detailed study of genome organisation is needed for major crops and their wild relatives.

Gene transfer method: In the direct gene transfer methods, the foreign gene of interest is delivered into the host plant cell without the help of a vector. The following are some of the common methods of direct gene transfer in plants:

(a) Chemical mediated Gene transfer- Certain chemicals like polyethylene glycol (PEG) and dextran sulphate induce DNA uptake into plant protoplasts.

(b) Microinjection- Here the DNA is directly injected into plant protoplasts or cells using fine tipped glass needle or micropipette.

(c) Electroporation-In this case, a pulse of high voltage is applied for protoplasts/cells/tissues, which makes transient pores in the plasma membrane which facilitates the uptake of foreign DNA.

(d) Particle Gun- In this method, the foreign DNA is coated (precipitated) on to the surface of minute gold or tungsten particles (1-3 micrometer) and bombarded (shot) on to the target tissue or cells using a particle gun (also called as gene gun/shot gun/micro projectile gun).

Transgenic Breeding: Individuals which are developed through genetic engineering are called transgenic. A transgenic may be a plant, an animal or a microbe. Foreign genes present in a modified organism is called transgene. Transgenic plants contain transgenes. Using techniques of genetic engineering and biotechnology, useful genes can now be transferred into plants from a wide range of organisms including unrelated plant species, microbes, animals and from DNA synthesized in the laboratory. In the development of transgenic, sexual process is bypassed.

Transgenic plants have been developed in various field crops, such as wheat, barley, oat, maize sugarcane, rapeseed, soybean, peanut, cotton, tobacco, tomato, potato, sunflower etc. BT-cotton, a transgenic, is now successfully grown by farmers in India. BT-cotton is insect resistant and high yielding. Some of the most outstanding limitations of transgenic breeding are that polygenic characters cannot be manipulated, instable performance, low frequency and costly method of crop improvement. In-spite of many limitations and practical difficulties, genetic engineering offers immense possibilities for improving crops that were unthinkable before.

Improved Seed: The primary objective of plant breeding is to develop superior varieties of crops. The benefits from superior varieties can only be realized when they are grown commercially on a large scale. Seeds of improved varieties must be multiplied at a large scale in order to make them available to farmers for large scale cultivation. Here the word “seed” refers to seed or any other propagating material used for raising a crop. For example, grain produced for general consumption is not seed; only grain produced for raising a crop would be known as ‘seed’.

On the other hand potato tubers produced for planting a new crop are known as seed potato. During multiplication of varieties for use as seed, it is essential that genetic purity of the variety must be maintained. If the genetic purity is not maintained, superiority of the variety is likely to be lost. In addition, for best results the farmer should use new pure seed every year in case of self-pollinated crops, and every year (hybrid varieties) or every few years (composite and synthetic varieties) in case of cross-pollinated crops. This would require maintenance of seeds of superior varieties in genetically pure state, which would be multiplied every year to supply new seed to the farmers.

The seed produced by the breeder who developed the variety, or by the institution where the variety was developed is the breeder seed. Foundation seed is the progeny of the breeder seed and is used to produce registered seed or certified seed.

Certified seed is grown by various agencies and is certified for use as seed by the State Seed Certification Agency.

The minimum standards for certification vary to some extent from one crop to another. To ensure availability of pure seed of different crops to farmers, elaborate seed programmes (production and distribution) exist in most of the countries. Our country also has a well-organized seed production and distribution programme in the form of National Seeds Corporation (NSC), State Seeds Corporation (SSC) and State Seed Certification Agency (SSCA). These organizations are responsible for seed certification and its distribution.

8.7 SUMMARY

Inheritance is the process by which genetic informations are passed from parent to child. This is why members of the same family tend to have similar characteristics. Most of our cells contain two sets of 23 chromosomes (they are diploid). An exception to this rule are the sex cells (egg and sperm), also known as gametes, which only have one set of chromosomes each (they are haploid). However, in sexual reproduction the sperm cell combines with the egg cell to form the first cell of the new organism in a process called fertilization. This cell (the fertilized egg) has two sets of 23 chromosomes (diploid) and the complete set of instructions needed to make more cells, and eventually a whole person. Each of the cells in the new person contains genetic material from the two parents. This passing down of genetic material is evident if you examine the characteristics of members of the same family, from average height to hair and eye colour to nose and ear shape, as they are usually similar. If there is a mutation in the genetic material, this can also be passed on from parent to child. This is why diseases run in families.

Mendelian inheritance is inheritance of biological features that follows the laws proposed by Gregor Johann Mendel in 1865 and 1866 and re-discovered in 1900. It was initially very controversial. When Mendel's theories were integrated with the Boveri-Sutton chromosome theory of inheritance by Thomas Hunt Morgan in 1915, they became the core of classical genetics.

Two genes are said to be under linkage, or linked, when they are located on the same chromosome. For example, research on the human genome discovered that the gene for factor III of clotting gene and the gene for factor V of clotting are located on the same chromosome (the human chromosome 1). However, the factor VII gene is not linked to those genes, since it is located on chromosome 13.

Linked alleles, for example, A-b and a-B, form the gametes A-b and a-B, which maintain the linkage of the alleles. This type of linkage is called complete linkage. However, in the first division of meiosis (meiosis I), the crossing over phenomenon may occur. Chromosomes from a pair of homologous chromosomes may exchange ends and certain once-linked alleles, for example, A-b and a-B, recombine to form different gametes, in this case, A-B and a-b. Crossing over a-B may happen when the arms of the chromatids of each homologous chromosomes are paired during meiosis. Matching portions of the ends of two non-sister chromatids (one from one homologous chromosome of the pair) break off and the pieces are exchanged, each of them becoming part of the arm of the other chromatid. For example, if the allele A is situated to one side of the arm relating to the point of breaking and the allele b is located on the other side, they will be separated and gametes A-B and a-b will be formed, instead of A-b and a-b. The percentage of recombinant gametes compared to normal gametes depends on the crossing over rate, which in turn depends on how far apart the given alleles are in the chromosome.

The plant breeding programs begin by selecting plants with superior characteristics. In traditional breeding programs commercial cultivars are produced by a series of crossing and selections. New cultivars can be produced by genetic engineering. The commercial rights of plant breeders are protected by legislation.

8.8 GLOSSARY

Gene: A unit of heredity composed of DNA occupying a fixed position on a chromosome (some viral genes are composed of RNA). A gene may determine a characteristic of an individual by specifying a polypeptide chain that forms a protein or part of a protein (structural gene); or encode an RNA molecule; or regulate the operation of other genes or repress such operation.

Allele: An **allele** is one of a pair of genes that appear at a particular location on a particular chromosome and control the same characteristic, such as blood type or colorblindness. **Alleles** are also called alleleomorphs. Your blood type is determined by the **alleles** you inherited from your parents.

Genetic inheritance: Inheritance is the process by which genetic information is passed on from parent to child. This is why members of the same family tend to have similar characteristics. Each cell in the body contains 23 pairs of chromosomes. One chromosome from each pair is **inherited** from your mother and one is **inherited** from your father. The chromosomes contain the **genes inherit** from parents. There may be different forms of the same **gene** – called alleles.

Heredity: Heredity is the passing of traits from parents to their offspring, either through asexual reproduction or sexual reproduction. This is the process by which an offspring cell or organism acquires or becomes predisposed to the characteristics of its parent cell or organism.

Crossing over: The exchange of segments between non-sister chromatids of homologous chromosomes during meiosis is called crossing over.

Plant Breeding: A science, an art and a technology which deals with genetic improvement of crop plants in relation to their economic use for mankind, also called as crop improvement.

Breeding Techniques: Various breeding procedures which are used for genetic improvement of crop plants in relation to their economic use.

Domestication: The process of bringing wild plants under human management referred to as plant domestication.

Plant Introduction: Transposition of crop plants from the place of their cultivation to suchareas where they never grown.

8.9 SELF ASSESSMENT QUESTIONS

8.9.1 Multiple choice questions:

1- Gregor Mendel was:
(a) An English scientist who carried out research with Charles Darwin
(b) An early 20th century Dutch biologist who carried out genetics research
(c) An Austrian monk
(d) An American geneticist

2- An allele is-
(a) One of four possible forms of a gene (b) A heterozygous genotype

(c) A homozygous genotype.
(d) One of several possible forms of a gene

3- In a two allele, one locus diploid system, True Breeding individuals are-
(a) Homozygous at one locus
(b) Heterozygous at one locus
(c) Always dominant
(d) Always recessive

4- Phenotype of an individual refers to the-
(a) Actual allele signal
(b) Actual physical appearance
(c) Genetic makeup
(d) Recessive allele

5- The idea that different pairs of alleles are passed to offspring independently is Mendel's principle of:
(a) Segregation
(b) Unit inheritance
(c) Independent assortment
(d) Blended inheritance

6**-** Who coined the term linkage-
(a) Mendel
(b) Correns
(c) De Vries
(d) Morgan

7- Mendel did not observe linkage due to-
(a) Crossing over
(b) Synapsis
(c) Mutation
(d) Independent assortment

8- The phenomenon of linkage was first observed in the plan-
(a) *Datura*
(b) *Mirabilis jalapa*
(c) *Lathyrus odoratus*
(d) *Pisum sativum*

9- How many linkage groups of chromosomes will be present in case of maize, if all its genes are mapped?
(a) 5
(b) 10
(c) 15
(d) 100

10- Polyploidy is induced through
(a) Irradiation
(b) Mutagenic chemicals
(c) Ethylene
(d) Colchicine

11- The quickest method of plant breeding is
(a) introduction
(b) Selection
(c) Hybridisation
(d) Mutation Breeding

12-The new varieties of plants are produced by
(a) Introduction and mutation
(b) Selection and hybridisation

(c) Mutation and Selection (d) Selection and Introduction

13- Pure line breed refers to
(a) heterozygosity only (b) homozygosity only
(c) homozygosity and self assortment (d) heterozygosity and linkage

8.9.1- Answer Keys: 1-(c), 2-(d), 3-(a), 4-(b), 5-(c), 6-(d), 7(d), 8(c), 9-(b), 10- (d), 11- (d), 12-(b), 13- (b).

8.10 REFERENCES

- Grafen, Alan; Ridley, Mark (2006). Richard Dawkins: How A Scientist Changed the Way We Think. New York, New York: Oxford University Press. p. 69. ISBN 0-19-929116-0.
- E. B. Ford (1960). Mendelism and Evolution (seventh ed.). Methuen & Co (London), and John Wiley & Sons (New York).
- Henig, Robin Marantz (2009). The Monk in the Garden : The Lost and Found Genius of Gregor Mendel, the Father of Modern Genetics. Houghton Mifflin. ISBN 0-395-97765-7. The article, written by an Austrian monk named Gregor Johann Mendel.
- Mendel's paper in English: Gregor Mendel (1865). "Experiments in Plant Hybridization".
- BRIMGES, C. B. 1916. Non-disjunction as proof of the chromosome theory of heredity. Genetics 1: 1-52; 107-163.
- William Bateson, E. R. Saunders, R. C. Punnett (1904) "Report II. Experimental studies in the physiology of heredity" Reports to the Evolution Committee of the Royal Society. http://archive.org/details/RoyalSociety. ReportsToTheEvolution Committee. Report Ii. Experimental
- Morton NE (1955). "Sequential tests for the detection of linkage". American Journal of Human Genetics **7** (3): 277–318. PMC 1716611. PMID 13258560.
- R. A. Fisher, and Balmukand, B. 1928. The estimation of linkage from the offspring of selfed heterozygotes. Journal of Genetics 20:79-92.
- Derivation of mapping function, from Introduction to Genetic Analysis. Griffiths, A. J. F.; Miller, J. H.; Suzuki, D. T.; Lewontin, R. C.; Gelbart, W. M. New York: W. H. Freeman & Co.; 1999.
- Mader, Sylvia (2007). Biology Ninth Edition. New York: McGraw-Hill. p. 209. ISBN 978-0-07-325839-3.
- Creighton H, McClintock B (1931). "A Correlation of Cytological and Genetical Crossing-Over in Zea Mays". Proc Natl Acad Sci USA **17** (8): 492–7. doi:10.1073/pnas.17.8.492. PMC 1076098. PMID 16587654.(Original paper)
- Harris Bernstein, Carol Bernstein and Richard E. Michod (2011). Meiosis as an Evolutionary Adaptation for DNA Repair. Chapter 19 in DNA Repair. Inna Kruman, editor. InTech Open Publisher. DOI: 10.5772/25117 http://www.intechopen.com/books/dna-repair/meiosis-as-an-evolutionary-adaptation-for-dna-repair

- Bernstein, H; Bernstein, C (2010). "Evolutionary origin of recombination during meiosis". BioSciene **60** (7): 498–505. doi:10.1525/bio.2010.60.7.5.
- Esposito, M (September 1978). "Evidence that Spontaneous Mitotic Recombination Occurs at the Two-Strand Stage". Proceedings of the National Academy of Sciences of the USA **75** (9): 4436–4440. doi:10.1073/pnas.75.9.4436.
- Kumar, A; Bassi, F; Paux, E (2012). "DNA repair and crossing over favor similar chromosome regions as discovered in radiation hybrid of Triticum". BMC Genomics **13** (339). doi:10.1186/1471-2164-13-339. Retrieved 14 March 2015.
- Smith, George P. (1976-01-01). "Evolution of Repeated DNA Sequences by Unequal Crossover". Science **191** (4227): 528–535.
- Metzenberg, Ab; et al. (May 1991). "Homology Requirements for Unequal Crossing Over in Humans". Genetics.
- Breeding Field Crops. 1995. Sleper and Poehlman. Page 3
- Piperno, D. R.; Ranere, A. J.; Holst, I.; Iriarte, J.; Dickau, R. (2009). "Starch grain and phytolith evidence for early ninth millennium B.P. maize from the Central Balsas River Valley, Mexico". PNAS. 106 (13): 5019–5024. doi : 10.1073/ pnas.0812525106 . PMC 2664021 . PMID 19307570 .
- Deppe, Carol (2000). Breed Your Own Vegetable Varieties. Chelsea Green Publishing. |page=237-244

8.11 SUGGESTED READINGS

- Peter J. Bowler (1989). The Mendelian Revolution: The Emergence of Hereditarian Concepts in Modern Science and Society. Johns Hopkins University Press.
- Atics, Jean. Genetics: The life of DNA. ANDRNA press.
- Reece, Jane B., and Neil A. Campbell. "Mendel and the Gene Idea." Campbell Biology. 9th ed. Boston: Benjamin Cummings / Pearson Education, 2011. 265.
- Griffiths AJF; Miller JH; Suzuki DT; Lewontin RC; et al. (1993). "Chapter 5". An Introduction to Genetic Analysis (5th ed.). New York: W.H. Freeman and Company. ISBN 0-7167-2285-2.
- Poehlman JM; Sleper DA (1995). "Chapter 3". Breeding Field Crops (4th ed.). Iowa: Iowa State Press. ISBN 0-8138-2427-3.
- General Plant Breeding by A.R. Dabholkar
- A text book of Plant breeding, by B.D. Singh, Kalyani publication, Ludhiana
- Cell Biology, Genetics and Plant Breeding by P.C.Trivedi

8.12 TERMINAL QUESTIONS

8.12.1 Short answer type Questions:

1. Why do children look like their parents?
2. Why do some children look more like their mother and others look more like their father?

3. How is the similarity between children and parents controlled?
4. What controls the development of an organism?
5. What is a gene and where is it located?
6. Do all organisms have the same number of genes?
7. Define crossing over. Give its significance.
8. What is the importance of crossing over?
9. Which selection methods will be suitable for maintaining purity of a variety in a self pollinated crop?

8.12.2 Long answer type Questions:

1. What two experimental innovations did Mendel use that allowed him to discover the laws of genetics?
2. What did Mendel conclude from his experiments?
3. Why Mendel's First Law of Genetics is called the "Law of Segregation"?
4. Why Mendel's Second Law of Genetics is called the "Law of Independent Assortment"?
5. What causes biologists to suspect that chromosomes are involved in the transmission of the hereditary material?
6. What is the relationship between the gene and the appearance of an organism (Genotype vs. Phenotype)?
7. What is gene linkage? Demonstrate it with examples.
8. What is crossing over? How is meiosis related to this phenomenon?
9. What is plant breeding? Describe briefly the various objective of Plant Breeding with suitable examples.
10. Discuss the various selection methods of plant breeding.

UNIT-9 THE CELL

Contents:

9.1 OBJECTIVES

After reading this unit student will be able to understand about-

- brief idea about the great diversity shown by cells in their shapes and sizes
- Also, to give an outline information about structures and purposes of basic components of prokaryotic and eukaryotic cells.
- To know about structure and function of DNA
- Organization and characteristics feature of genetic code.
- Basics of plant tissue culture (Tools, techniques, media and culture type)

9.2 INTRODUCTION

The basic structural and functional unit of cellular organization is the *cell*. Within a selective and relative semi permeable membrane, it contains a complete set of different kinds of units necessary to permit its own growth and reproduction from simple nutrients. All organisms, more complex than viruses, consist of cells, yet they consist of a strand of nucleic acid, either DNA or RNA, surrounded by a protective protein coat (the capsid). The word cell is derived from the Latin word *cellula*, which means small compartment. Hooke published his findings in his famous work, *Micrographia*. Actually, he only observed cell walls because cork cells are dead and without cytoplasmic contents. A.G. Loewy and P. Siekevitz have defined cell as "*A unit of biological activity delimited by a semi permeable membrane and capable of self reproduction in a medium free of other living organisms*". John Paul has defined the cell as "The simplest integrated organization in living systems, capable of independent survival".

On the basis of internal organization and architecture, all cells can be subdivided into two major classes, prokaryotic cells and eukaryotic cells. Cells which have the unit membrane bound nuclei are called eukaryotic, whereas cells that lack a membrane bound nucleus are prokaryotic. Besides the nucleus, the eukaryotic cells have other membrane bound organelles (small organs) like the Endoplasmic reticulum, Golgi complex, Lysosomes, Mitochondria, Microbodies and Vacuoles. The prokaryotic cells lack such unit membrane bound organelles.

9.3 HISTORICAL BACKGROUND

Ancient Greek philosophers such as Aristotle 384-322 B.C and Paracelsus concluded that "*All animals and plants, however, complicated, are constituted of a few elements which are repeated in each of them*". They were referring to macroscopic structures of an organism such as roots, leaves and flowers common to different plants, or segments and organs that are repeated in the animal kingdom. Many centuries later, owing to the invention of magnifying lenses, the world of microscopic dimensions was discovered. Da Vinci (1485) recommended the uses of lenses in viewing small objects. In 1558, Swiss biologist, Conard Gesner (1516-1565) published results on his studies on the structure of a group of protists called foraminifera. His sketches of these protozoa included so many details that they could only have been made if he had used form of magnifying lenses. Perhaps, this is earliest recorded use of a magnifying instrument in a biological study.

Further growth and development of cell biology are intimately associated with the development of optical lenses and to the combination of these lenses in the construction of the compound microscope. Thus, the invention of the microscope and its gradual improvement went hand-in-hand with the development of cell biology.

Growth of Cell Biology during 16th and 18th Centuries

The first useful compound microscope was invented in 1590 by Francis Janssen and Zacharias Janssen. Their microscope had two lenses and total magnifying power between 10X and 30X. Such types of microscopes were called “flea glasses", since they were primarily used to examine small whole organisms such as fleas and other insects. In 1610, an Italian Galileo Galilei (1564-1642) invented a simple microscope having only one magnifying lens. This microscope was used to study the arrangement of the facets in compound eye of insects.

The Italian microanatomist Marcello Malpighi (1628-1694) was among the first to use a microscope to examine and describe thin slices of animal tissues from such organs as the brain, liver, kidney, spleen, lungs and tongue. He also studied plant tissues and suggested that they were composed of structural units that he called “utricles”. An English microscopist Robert Hooke (1635-1703) is credited with coining the term cell in 1665. He examined a thin slice cut from a piece of dried cork under the compound microscopes which were built by him.

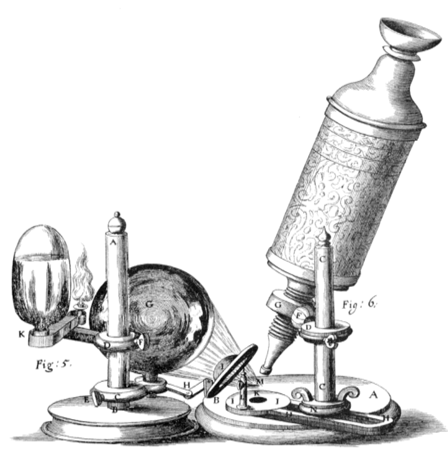


Fig. 9.1: Hooke's compound microscope

9.4 SIZE AND STRUCTURE OF CELL

There are many cells in an individual, which performs several functions throughout the life. The different types of cell include- prokaryotic cell, plant and animal cell. The size and the shape of the cell range from millimeter to microns, which are generally based on the type of function that it performs. A cell generally varies in their shapes. A few cells are in spherical, rod, flat, concave, curved, rectangular, oval and etc. These cells can only be seen under microscope.

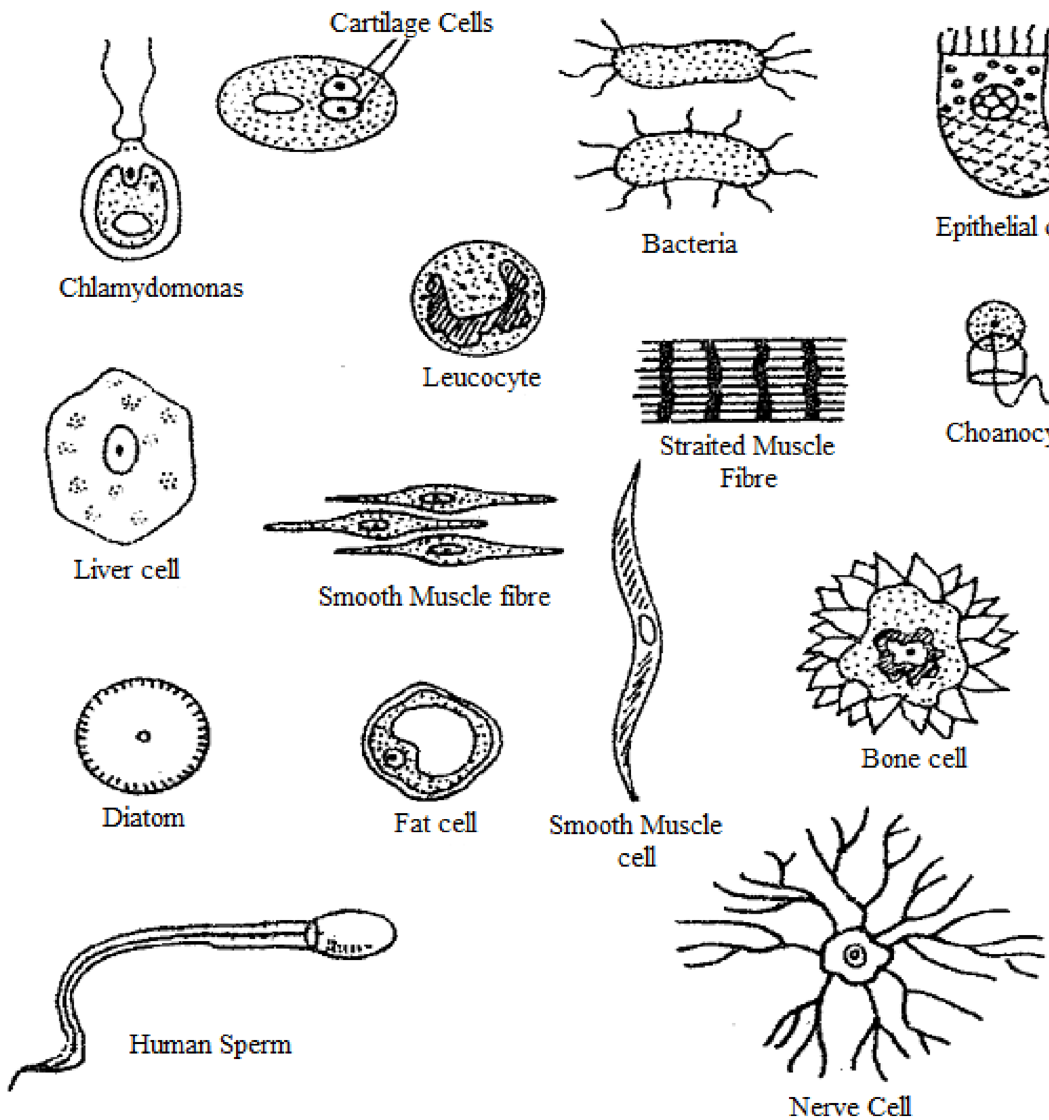


Fig. 9.2 Different types of cells

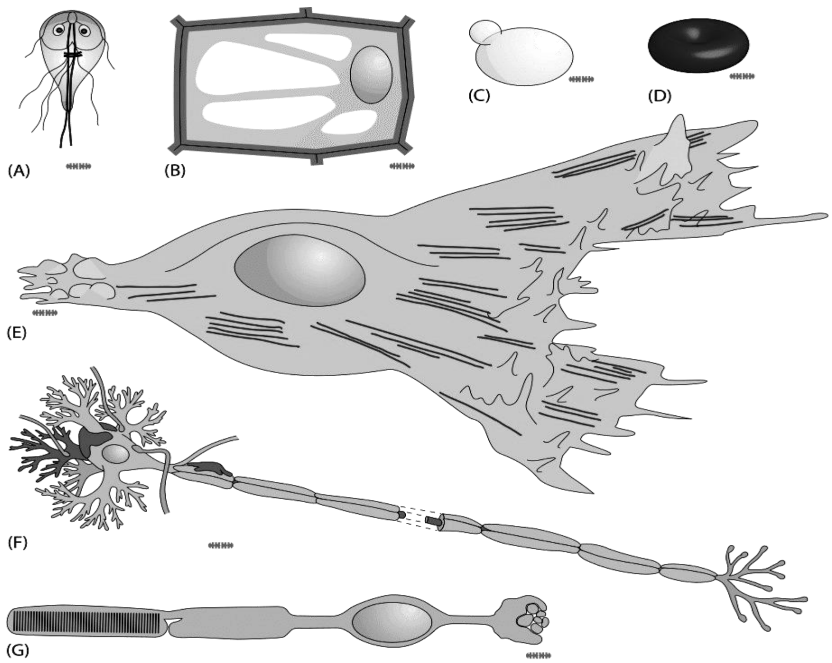


Fig. 9.3 : Several different types of cells all referenced to a standard E. coli ruler of 1 micron (A) The protist *Giardia lamblia*, (B) a plant cell, (C) a budding yeast cell, (D) a red blood cell, (E) a fibroblast cell, (F) a eukaryotic nerve cell, and (G) a rod cell from the retina.

Cell Size

One may wonder why all cells are so small. If being able to store nutrients, is beneficial to the cell, how come there are no animals existing in nature with huge cells? Physical limitations prevent this from occurring. A cell must be able to diffuse gases and nutrients in and out of the cell. A cell's surface area does not increase as quickly as its volume, and as a result a large cell may require more input of a substance or output of a substance than it is reasonably able to perform. Worse, the distance between two points within the cell can be large enough that regions of the cell would have trouble communicating, and it takes a relatively long time for substances to travel across the cell.

That is not to say large cells don't exist. They are, once again, less efficient at exchanging materials within themselves and with their environment, but they are still functional. These cells typically have more than one copy of their genetic information, so they can manufacture proteins locally within different parts of the cell. Features of such large cells are following:

1. Is limited by need for regions of cell to communicate
2. Diffuse oxygen and other gases
3. Transport of mRNA and proteins
4. Surface area to volume ratio limited

Larger cells typically:

a) Have extra copies of genetic information

b) Have slower communication between parts of cell

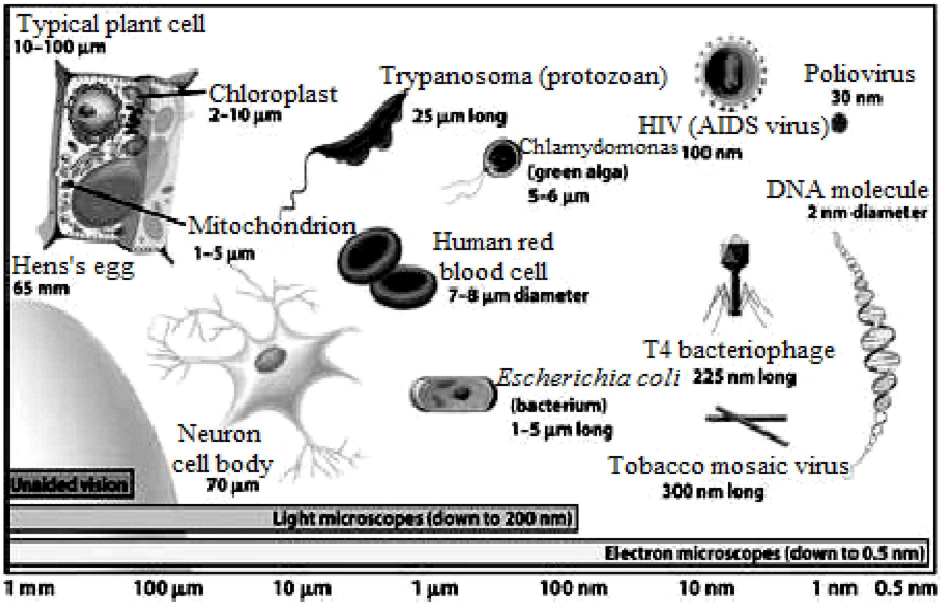


Fig. 9.4 Various types of cells ranging in different sizes

The shapes of cells are quite varied with some, such as neurons, being longer than they are wide and others, such as parenchyma (a common type of plant cell) and erythrocytes (red blood cells) being equidimensional. Some cells are encased in a rigid wall, which constrains their shape, while others have a flexible cell membrane (and no rigid cell wall).

The size of cells is also related to their functions. Eggs (or to use the Latin word, ova) are very large, often being the largest cells an organism produces. The large size of many eggs is related to the process of development that occurs after the egg is fertilized, when the contents of the egg (now termed a zygote) are used in a rapid series of cellular divisions, each requiring tremendous amounts of energy that is available in the zygote cells. Later in life the energy must be acquired, but at first a sort of inheritance/trust fund of energy is used. Cells range in size from small bacteria to large, unfertilized eggs laid by birds and dinosaurs. Here are some measurements and conversions that will aid your understanding of biology.

1 meter = 100 cm = 1,000 mm = 1,000,000 µm = 1,000,000,000 nm
1 centimeter (cm) = 1/100 meter = 10 mm
1 millimeter (mm) = 1/1000 meter = 1/10 cm
1 micrometer (µm) = 1/1,000,000 meter = 1/10,000 cm
1 nanometer (nm) = 1/1,000,000,000 meter = 1/10,000,000 cm

9.5 PROKARYOTIC AND EUKARYOTIC CELL

Body of all living organisms except virus has cellular organization and may contain one or many cells. The organisms with only one cell in their body are known as unicellular (bacteria, protozoa etc.) and organisms with many cells in their body are known as multicellular organisms (most plants and animals). Any cellular organization may contain only one type of cell from the following types:

A- Prokaryotic cell
B- Eukaryotic cell

These terms were suggested by Hans Ris in the 1960's.

A: PROKARYOTIC CELL

The prokaryotic (Gr., *pro*= primitive or before and *karyon* = nucleus) are small, simple, and most primitive. They are probably first to come into existence perhaps 3.5 billion years ago. These cells occur in bacteria (i.e., Mycoplasma, Cyanobacteria etc). Prokaryotic cell is a one envelope system organized in depth. It consists of central nuclear components surrounded by cytoplasmic ground substance, with whole enveloped by a plasma membrane. The cytoplasm of prokaryotic cell lacks nuclear envelope and any other cytoplasmic membrane and well defined cytoplasmic organelles.

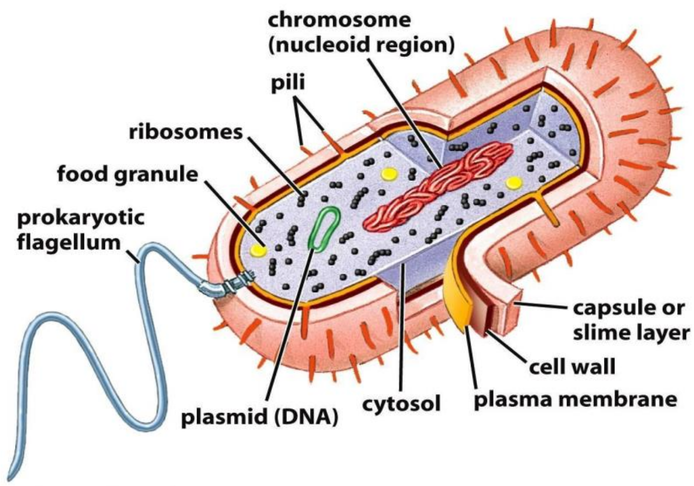


Fig.9.5 Structure of a prokaryotic cell

Bacteria

The bacteria are amongst smallest organisms, most primitive, prokaryotic and microscopic organisms. They occur almost everywhere; in air, water, soil and inside other organisms. They lead either autotrophic or heterotrophic mode of existence.

1. Size of Bacteria: It ranges between 1-3µm and are barely visible under light microscope.

2. Shape of Bacteria: The three basic bacterial shapes are:

Cocci – (spherical shaped). e.g., *Diplococcus pneumonia, Streptococcus pyogenes* etc.

Bacilli – (rod-shaped) e.g. *Mycobacterium, Clostridium botylinum* etc.

Spirilla (spiral or twisted) e.g. *Treponema pallidum* etc
However pleomorphic bacteria can assume several shapes.

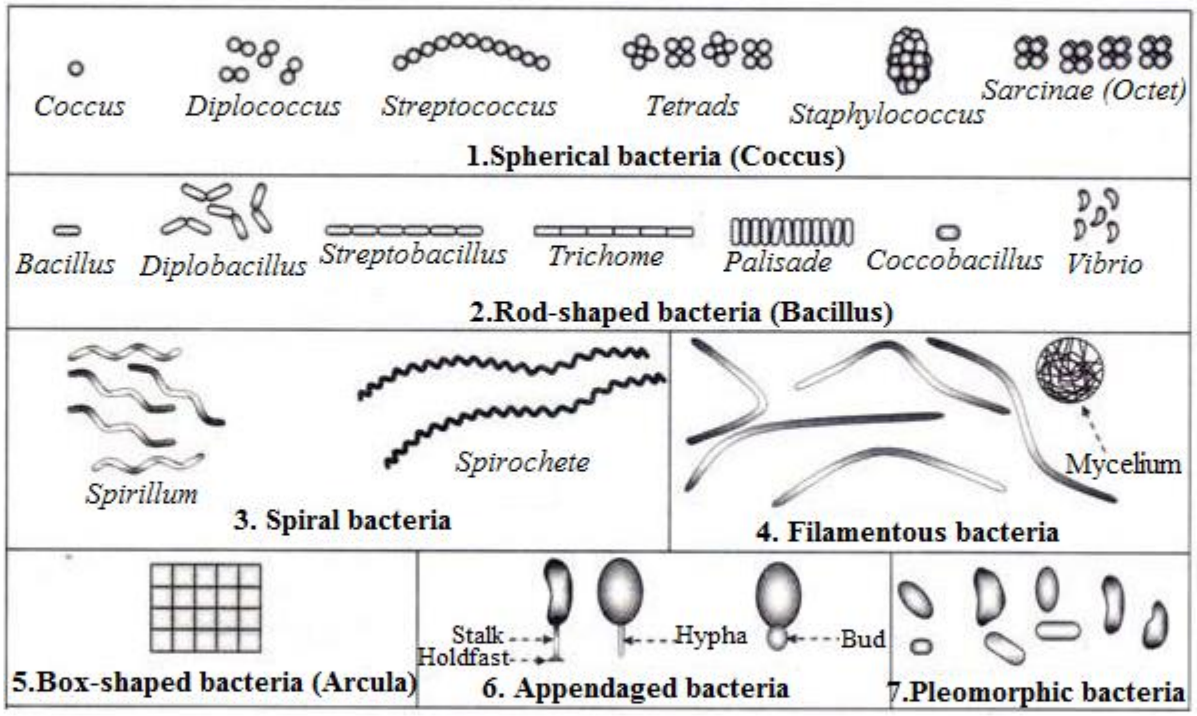


Fig. 9.6 Different shapes of bacteria

3. Structure of Bacteria:

(i) Plasma membrane- It is an ultra thin membrane 6-8 nm thick, chemically comprised of molecules of lipids and proteins, arranged in a fluid mosaic pattern. Infoldings in it gives rise to two main types of structures:

(a) Mesosomes- (Also known as Chondriods); are extensions involving complex whorls of convoluted membranes. They increase surface area of plasma membrane and enzymatic contents.

(b) Chromatophores- These are photosynthetic pigment- bearing membranous structures of photosynthetic bacteria and are present as vesicles, thylakoids, tubes etc.

(ii) Cell Wall- It is strong and rigid and covers plasma membrane to provide chemical protection and characteristic shape of bacteria. It is made up of peptidoglycan and contains muramic acid.

(iii) Capsule- In some bacteria, cell wall is surrounded by an additional slime or gel layer called capsule that acts as protective layer against viruses and phagocytes.

(iv) Cytoplasm- It is the ground substance surrounded by plasma membrane and is site of all metabolic activities of bacteria. It consists of water, proteins, enzymes, different types of RNA molecules and reserve materials like glucogen, volutin and sulphur. The dense nuclear areas of cytoplasm contain 70S ribosomes granules, composed of RNA and protein and are the site of protein synthesis.

(v) Nucleoids- The nuclear membrane includes a single, circular and double stranded DNA molecule often called as bacterial chromosome. It is not separated by nuclear membrane and is usually concentrated in a specific clear region of the cytoplasm called nucleoid. It has no ribosomes, nucleolus and histone proteins.

(vi) Plasmids – Many species of bacteria may also carry extrachromosomal genetic elements in the form of small, circular, and closed DNA molecules called plasmids. They produce antibiotically active protein or colicins which inhibit the growth of other bacterial strain in their vicinity. They may also act as sex or fertility factors (F factor) which stimulate bacterial conjugation. R factors are also plasmid carrying genes for resistance to drugs.

(vii) Flagella- Many bacteria are motile and contain one or more flagella for cellular locomotion. They are 15-20nm in diameter and up to 20μm long. e.g., *E.coli* etc

4. Nutrition: They show diversity in their nutrition from being chemosynthetic, to photosynthetic; but most of them are heterotrophic. Heterotrophic bacteria are mostly either saprophytic or parasitic. Parasitic lives on the bodies of other organisms. Most bacteria are pathogenic.

5. Mode of Respiration: It is of both types; aerobic (which respire in the presence of oxygen.eg *Lactobacillus*) and anaerobic (which respire in the absence of oxygen. e.g. *Pseudomonas*).

6. Reproduction: Bacteria reproduce through asexually by binary fission and endospore formation and sexually by conjugation. In conjugation, genetic exchange and recombination occurs through sex pili, but this is a form of horizontal gene transfer and is not a replicative process, simply involving the transference of DNA between two cells.

B: Eukaryotic Cell

The Eukaryotic cells are essentially two envelope systems and they are very much larger than prokaryotic cells. Secondary membranes envelop the nucleolus and other internal organelles and to a great extent they pervade the Cytoplasm as the Endoplasmic reticulum. The Eukaryotic cells are true cells which occur in the plants (from algae to angiosperms) and the animal (from Protozoa to mammals). Though the Eukaryotic cells have different shape, size, and physiology; all the cells are typically composed of plasma membrane, cytoplasm and its organelles, viz. Mitochondria, Endoplasmic reticulum, ribosomes, Golgi apparatus etc; and a true nucleus. Here the nuclear contents, such as DNA, RNA, Nucleoproteins and Nucleolus remain separated from the Cytoplasm by the thin perforated nuclear membranes.

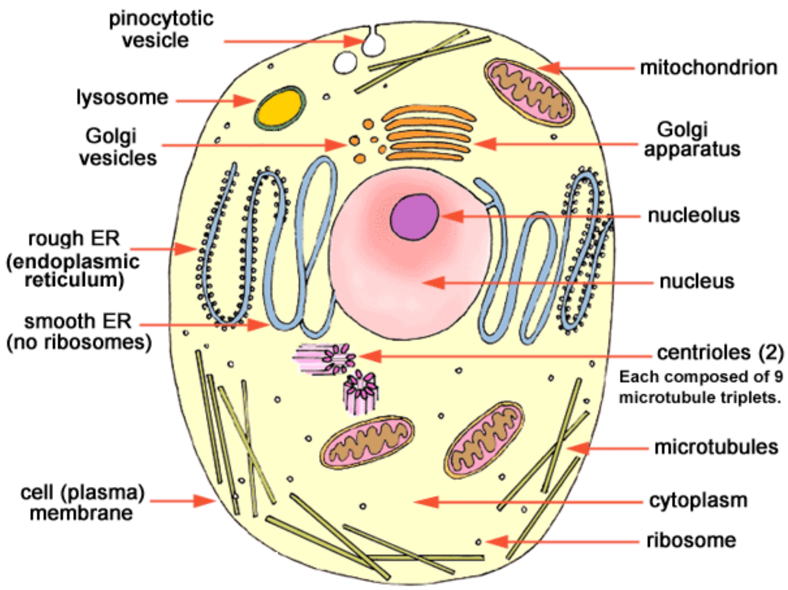


Fig.9.7 Structure of a Eukaryotic cell

The following table features different organelles of cell with their location, description and functions.

ORGANELLE	LOCATION	DESCRIPTION	FUNCTION
Cell wall	Plant, not animal	Outer layer rigid, strong, stiff made of cellulose	Support (grow tall) protection allows H2O, O2, CO2 to pass into and out of cell
Cell membrane	Both plant/animal	Plant - inside cell wall animal - outer layer; cholesterol selectively permeable	Support protection controls movement of materials in/out of cell barrier between cell and its environment maintains homeostasis
Nucleus	Both plant/animal	Large, oval	Controls cell activities
Nuclear membrane	Both plant/animal	Surrounds nucleus selectively permeable	Controls movement of materials in/out of nucleus
Cytoplasm	Both plant/animal	Clear, thick, jellylike material and organelles found inside cell membrane	Supports /protects cell organelles
Endoplasmic reticulum (E.R.)	Both plant/animal	Network of tubes or membranes	Carries materials through cell

Ribosome	Both plant/animal	Small bodies free or attached to E.R.	Produces proteins
Mitochondrion	Both plant/animal	Bean-shaped with inner membranes	Breaks down sugar molecules into energy
Vacuole	Plant - few/large animal - small	Fluid-filled sacs	Store food, water, waste (plants need to store large amounts of food)
Lysosome	Plant - uncommon animal - common	Small, round, with a membrane	Breaks down larger food molecules into smaller molecules digests old cell parts
Chloroplast	Plant, not animal	Green, oval usually containing chlorophyll (green pigment)	Uses energy from sun to make food for the plant (photosynthesis)

Animal Cell

All animals consist of eukaryotic cells. Animal cells are distinct from those of other eukaryotes, most notably plants, as they lack cell walls and chloroplasts and have smaller vacuoles. Due to the lack of a cell wall, animal cells can adopt a variety of shapes. A phagocytic cell can even engulf other structures. There are many other types of cell. For instance, there are approximately 210 distinct cell types in the adult human body.

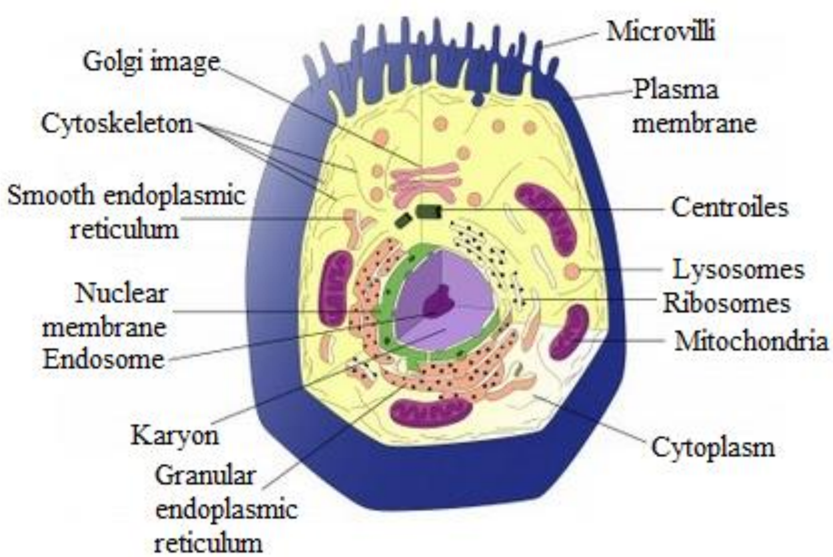


Fig.9.8 Structure of a typical animal cell

Plant Cell

1. Most of the organelles and other parts of the cell are common to all Eukaryotic cells. Cells from different organisms have an even greater difference in structure
2. Plant cells have three additional structures not found in animal cells:

(a) Cellulose cell walls
(b) Chloroplasts (and other plastids)
(c) A Central Vacuole

Cellulose cell wall

1. One of the most important features of all plants is presence of a cellulose cell wall.
2. Fungi such as Mushrooms and Yeast also have cell walls, but these are made of chitin.
3. The cell wall is freely permeable (porous), and so has no direct effect on the movement of molecules into or out of the cell.
4. The rigidity of their cell walls helps both to support and protect the plant.
5. Plant cell walls are of two types:

(a) Primary (cellulose) cell wall - While a plant cell is being formed, a middle lamella made of pectin, is formed and the cellulose cell wall develops between the middle lamella and the cell membrane. As the cell expands in length, more cellulose is added, enlarging the cell wall. When the cell reaches full size, a secondary cell wall may form.

(b) Secondary (lignified) cell wall - The secondary cell wall is formed only in woody tissue (mainly xylem). The secondary cell wall is stronger and waterproof and once a secondary cell wall forms, a cell can grow no more – it is dead.

Vacuoles

1. The most prominent structure in plant cells is the large vacuole.
2. The vacuole is a large membrane-bound sac that fills up much of most plant cells.
3. The vacuole serves as a storage area, and may contain stored organic molecules as well as inorganic ions.
4. The vacuole is also used to store waste. Since plants have no kidney, they convert waste to an insoluble form and then store it in their vacuole - until autumn.
5. The vacuoles of some plants contain poisons (e.g. tannins) that discourage animals from eating their tissues.
6. Whilst the cells of other organisms may also contain vacuoles, they are much smaller and are usually involved in food digestion.

Chloroplasts (and other plastids)

1. A characteristic feature of plant cells is the presence of plastids that make or store food.
2. The most common of these are chloroplasts – the site of photosynthesis.
3. Each chloroplast encloses a system of flattened, membranous sacs called thylakoids, which contain chlorophyll.
4. The thylakoids are arranged in stacks called Grana.
5. The space between the Grana is filled with cytoplasm-like Stroma.
6. Chloroplasts contain cp DNA and 70S ribosomes and are semi-autonomous organelles.

7. Other plastids store reddish-orange pigments that colour petals, fruits, and some leaves.

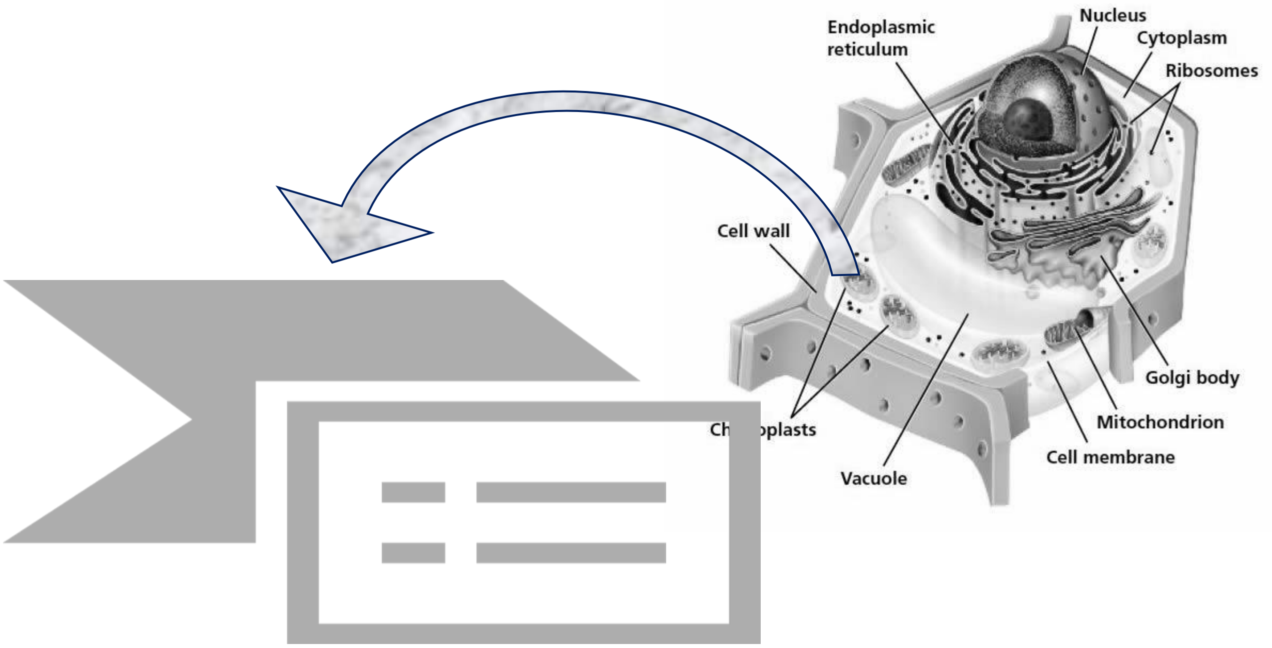


Fig.9.9 Structure of a Chloroplast and a typical plant cell

Plant cells are quite different from the cells of the other eukaryotic organisms. Their distinctive features are:

1. A large central vacuole (enclosed by a membrane, the Tonoplast), which maintains the cell's turgor and controls movement of molecules between the cytosol and sap.
2. A primary cell wall containing cellulose, hemicellulose and pectin, deposited by the protoplast on the outside of the cell membrane; this contrasts with the cell walls of fungi, which contain chitin, and the cell envelopes of prokaryotes, in which peptidoglycans are the main structural molecules.
3. The plasmodesmata, linking pores in the cell wall that allow each plant cell to communicate with other adjacent cells; this is different from the functionally analogous system of gap junctions between animal cells.
4. Plastids, especially chloroplasts that contain chlorophyll, the pigment that gives plants their green color and allows them to perform photosynthesis.
5. Bryophytes and seedless vascular plants lack flagella and centrioles except in the sperm cells. Sperm of cycads and Ginkgo are large, complex cells that swim with hundreds to thousands of flagella.
6. Conifers (Pinophyta) and flowering plants (Angiospermae) lack the flagella and centrioles that are present in animal cells.

9.6 CELL DIVISION

There are two types of cell division known which is mitosis (or indirect cell division) and meiosis (or reductional cell division). Mitosis occurs in somatic cells where as meiosis occurs in reproductive cells or gametes. Beside this there is another type of cell division called as **Amitosis** (**or direct cell division)** which occurs in unicellular organism such as protozoa and also in yeast. Amitosis also occurs in foetal membrane of vertebrates. There is no condensation of chromosomes and spindle formation in this type of cell division.

Advantage of amitosis is that it occurs in very short period of time and disadvantage is that there is no possibility of genetic recombination. During amitosis, nucleus elongates and assumes dumbbell-shape followed by splitting of nucleus by constriction. Along with this, constriction in cytoplasm occur which results in division of cell into two.

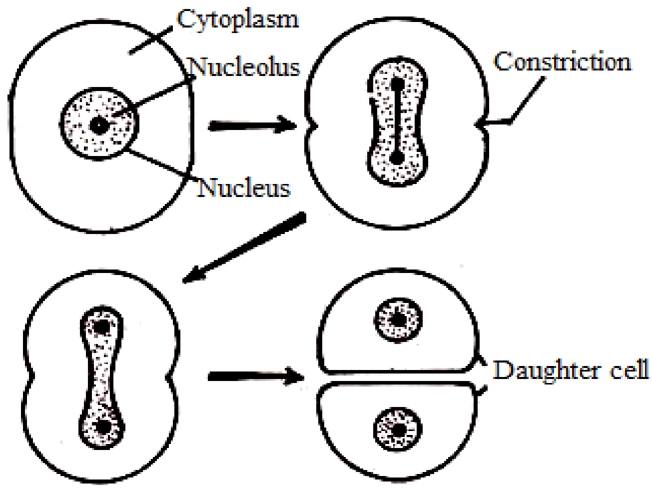


Fig.9.10 Diagrammatic representation of amitosis

Amitosis is characterized by:

1. Intact nuclear envelope is found throughout the division.
2. Chromatin does not condense into definite chromosomes.
3. A spindle is not formed.
4. Chromatin distribution occurs unequally which causes abnormalities in metabolism and reproduction.
5. Cytokinesis may or may not follow karyokinesis.

The primary concern of cell division is the maintenance of the original cell's genome. Before division can occur, the genomic information that is stored in chromosomes must be replicated, and the duplicated genome must be separated cleanly between cells. A great deal of cellular infrastructure is involved in keeping genomic information consistent between generations.

The importance of cell division can be appreciated by realizing the following facts:

1. Cell division is a prerequisite for the continuity of life and forms the basis of evolution to various life forms.
2. In unicellular organisms, cell division is the means of asexual reproduction, which produces two or more new individuals from the mother cell. The group of such identical individuals is known as **clone**.
3. In multicellular organisms, life starts from a single cell called zygote (fertilized egg). The zygote transforms into an adult that is composed of millions of cells formed by successive divisions.
4. Cell division is the basis of repair and regeneration of old and worn out tissues.

9.6.1 Mitosis

The mitosis is a part of somatic cell division which includes the division of the nucleus (called mitosis or karyokinesis) and the division of the cytoplasm (called cytokinesis). **Strasburger** (1875), a German botanist, was the first to work out the details of mitosis. Later on, **W. Flemming** (1879) discovered it in animal cells. The term mitosis was coined by **Flemming** (1882). Mitosis can be studied best in the root tip and shoot tip of several plants. But the most favourable material is the apices of onion roots.

Mitosis is a form of eukaryotic cell division that produces two daughter cells with the same genetic component as the parent cell. Chromosomes replicated during the S phase, are divided in such a way as to ensure that, each daughter cell receives a copy of every chromosome.

In actively dividing animal cells, the whole process takes about one hour. The replicated chromosomes are attached to a 'mitotic apparatus' that aligns them and then separates the sister chromatids to produce an even partitioning of the genetic material. This separation of the genetic material in a mitotic nuclear division (or **karyokinesis**) is followed by a separation of the cell cytoplasm in a cellular division (or **cytokinesis**) to produce two daughter cells.

In some single-celled organisms mitosis forms the basis of asexual reproduction. In diploid multicellular organisms, sexual reproduction involves the fusion of two haploid gametes to produce a diploid zygote. Mitotic divisions of the zygote and daughter cells are responsible for the subsequent growth and development of the organism. In the adult organism, mitosis plays a role in cell replacement, wound healing and tumour formation. In mitosis, the metabolic nucleus passes through a complicated system of changes in the form of four different stages, viz., prophase, metaphase, anaphase and telophase.

Karyokinesis: Karyokinesis is the name of nuclear division. It has been divided into five phases; Prophase, Prometaphase, Metaphase, Anaphase and Telophase. Some important aspects of all these stages are discussed below.

1. Prophase

- It is the first phase of mitotic karyokinesis in which chromatin fibres condense to form chromosomes. Prophase has three sub phases i.e. early, middle and late.
- Nucleus becomes spherical and cytoplasm becomes more viscous.

- The chromatin slowly condenses into well-defined chromosomes.
- Each chromosome appears as two sister chromatids joined at the centromere.

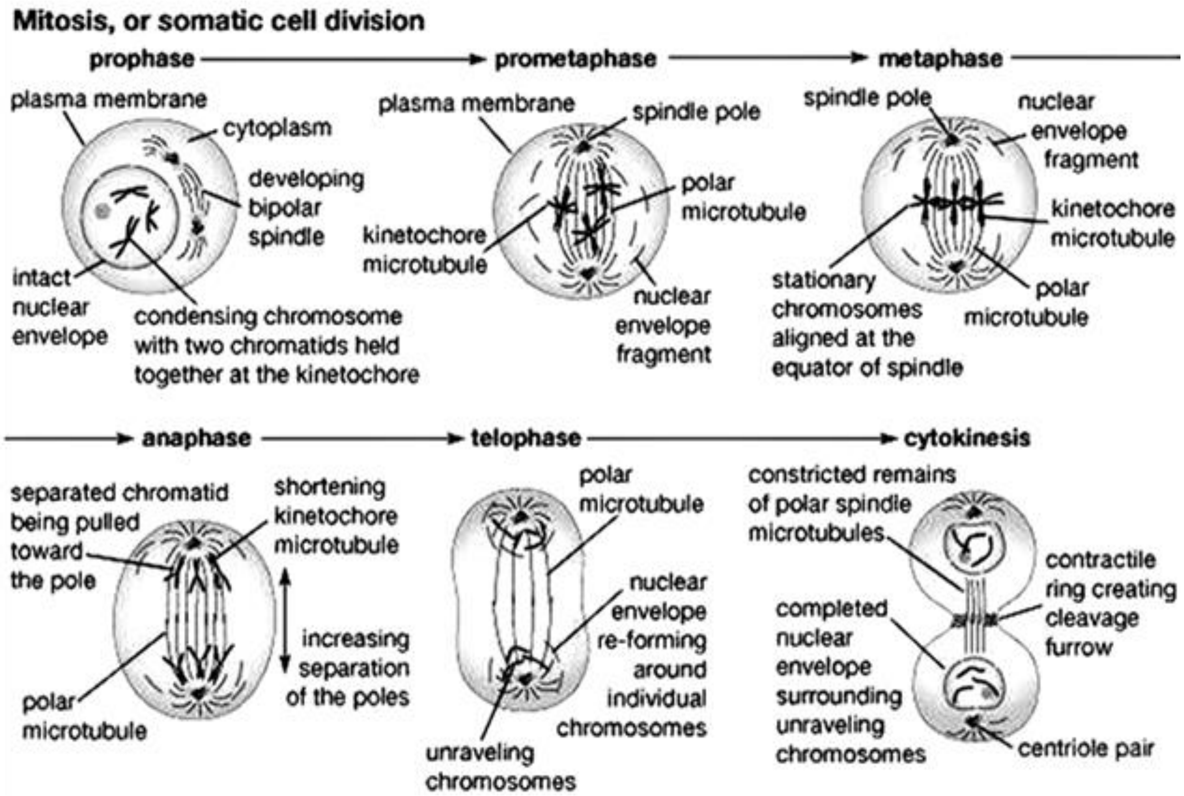


Fig. 9.11: Different stages of karyokinesis and cytokinesis

2. Prometaphase

- Nuclear envelop breaks down into membrane vesicles and the chromosomes set free into the cytoplasm.
- Chromosomes are attached to spindle microtubules through kinetochores. Nucleolus disappears.

3. Metaphase

- Kinetochore microtubules align the chromosomes in one plane to form metaphasic plate or equatorial plate. The process of formation of metaphasic plate is called **congression**.
- Centromeres lie on the equatorial plane while the chromosome arms are directed away from the equator called **auto orientation**.
- Smaller chromosomes remain towards the centre while larger ones occupy the periphery.

4. Anaphase

- Chromosomes split simultaneously at the centromeres so that the sister chromatids separate.
- The separated sister chromatids move towards opposite poles.
- At the end of anaphase, two groups of single stranded chromosomes are formed.

5. Telophase

- In this stage of karyokinesis, reformation of nuclei occurs.
- Daughter chromosomes arrive at the poles.
- Nuclear envelope reforms around each chromosome cluster of each pole.
- Formation of nucleolus and nuclear membrane occur.
- It is considered as the reverse of prophase.

6. Cytokinesis: or C-phase is the division of parent cell having undergone karyokinesis to produce two daughter cells each with a daughter nucleus. It is the cytoplasmic division that starts during mid-anaphase and completed by the end of telophase. Animal cell cytokinesis significantly differs from plant cell cytokinesis. It takes place by two bare different methods i.e. **cell plate** method and **cleavage** or cell furrowing method.

(a) Cell plate cytokinesis: It occurs in plant cells. The spindle fibres persist at equatorial plane. The Golgi vesicles fuse at the centre to form barrel-shaped **phragmoplast**. Further addition of vesicles causes the phragmoplast to grow centrifugally till it meets with plasma membrane of the mother cell. The contents of phragmoplast solidify to become cell plate or future middle **lamella** which separates the two daughter cells. The daughter protoplast secretes primary wall materials on both sides of the cell plate or middle lamella.

(b) Cleavage cytokinesis: It occurs in animal cells and pollen mother cells of some angiosperms. In this process, a cleavage furrow appears at the middle, which gradually deepens and breaks the parent cell into two daughter cells. A special structure called **midbody** is formed in the centre, and it is a centripetal process.

9.6.2 Meiosis

Meiosis (from Greek, meiosis, which means lessening) is a specialized type of cell division that reduces the chromosome number by half, creating four haploid cells, each genetically distinct from the parent cell that gave rise to them. This process occurs in all sexually reproducing single-celled and multicellular eukaryotes, including animals, plants, and fungi. It is the form of eukaryotic cell division (reductional division) which occurs during the process of formation of gametes in sexually reproducing organisms and produces haploid sex cells or gametes from diploid cells. The process also occurs during formation of spores in some organisms. In meiosis a diploid cell (2N) undergoes two successive divisions to form four haploid (N) daughter cells. The haploid cells give rise to gametes.

Meiosis was discovered and described for the first time in sea urchin eggs in 1876 by the German biologist **Oscar Hertwig**. It was described again in 1883, at the level of chromosomes, by the Belgian embryologist **Edouard Van Beneden**, in Ascaris roundworm eggs. While working on the horse threadworm (*Parascaris equorum*), he observed that there were twice as many chromosomes visible during mitosis in the fertilized egg as there had been in the sperm and egg nuclei before the mitosis. By this observation, he concluded that the contribution of each of the female and male gametes was half the chromosome number to the zygote. **A. Weismann**

(German biologist) suggested in 1887 that in each generation there must occur reduction division at some stage in which the chromosome number is reduced to half. **Flemming** (1887) and **Strasburger** (1888) observed that two nuclear divisions take place in rapid succession just prior to the formation of mature eggs and sperms in animals and formation of pollen grains in angiosperms. The entire process of reduction division leading to the formation of gametes was termed as "meiosis" in 1905.

In all organisms the chromosomes remain in pairs. The organisms reproducing asexually multiply by mitosis. Thus, there exists no chance of alteration of chromosome number. On the contrary, sexual reproduction demands contribution from two individuals. Thus there lies a risk of chromosomal imbalance. The process of meiosis helps to avert this probability by reducing the number of chromosomes to half. It may happen after gametic union (as in sporozoa) or before fertilization (in all higher organisms). In higher organisms, therefore, mitosis occurs in both somatic and germ cells but meiosis takes place in the germ cells alone and only during the formation of gametes. The process takes the form of one DNA replication followed by two successive nuclear and cellular divisions (Meiosis I and Meiosis II). As in mitosis, meiosis is preceded by a process of DNA replication that converts each chromosome into two sister chromatids.

Meiosis is divided into meiosis I and meiosis II which are further divided into Karyokinesis I and Cytokinesis I and Karyokinesis II and Cytokinesis II respectively. The preparatory steps that lead up to meiosis are identical in pattern and name to interphase of the mitotic cell cycle. Interphase is divided into three phases: Growth 1 phase, synthesis phase, and growth 2 phase.

(1) Growth 1 (G1) phase: In this very active phase, the cell synthesizes its vast array of proteins, including the enzymes and structural proteins it will need for growth. In G1, each of the chromosomes consists of a single linear molecule of DNA.

(2) Synthesis (S) phase: The genetic material is replicated; each of the cell's chromosomes duplicates to become two identical sister chromatids attached at a centromere. This replication does not change the ploidy of the cell since the centromere number remains the same. The identical sister chromatids have not yet condensed into the densely packaged chromosomes visible with the light microscope. This will take place during prophase-I in meiosis.

(3) Growth 2 (G2) phase: G2 phase as seen before mitosis is not present in meiosis. Meiotic prophase corresponds most closely to the G2 phase of the mitotic cell cycle.

Interphase is followed by meiosis I and then meiosis II. Meiosis I separates homologous chromosomes, each still made up of two sister chromatids, into two daughter cells, thus reducing the chromosome number by half. During meiosis II, sister chromatids decouple and the resultant daughter chromosomes are segregated into four daughter cells. For diploid organisms, the daughter cells resulting from meiosis are haploid and contain only one copy of each chromosome.

Meiosis I: It is the first division of meiosis where a diploid cell divides into two daughters each having half the number of replicated chromosomes. Meiosis I segregates homologous chromosomes, which are joined as tetrads (2n, 4c), producing two haploid cells (n chromosomes, 23 in humans) each contain chromatid pairs (1n, 2c). Because the ploidy is reduced from diploid to haploid, meiosis-I is referred to as a **reductional division**. The first meiotic division consists of four stages; Prophase I, Metaphase I, Anaphase I and Telophase I.

1. Prophase I: It is typically the longest phase of meiosis. During prophase I, homologous chromosomes pair and exchange DNA (homologous recombination). This often results in chromosomal crossover. This process is critical for pairing between homologous chromosomes and hence for accurate segregation of the chromosomes at the first meiosis division. The paired and replicated chromosomes are called bivalents or tetrads, which have two chromosomes and four chromatids, with one chromosome coming from each parent. The process of pairing the homologous chromosomes is called synapsis. At this stage, non-sister chromatids may cross-over at points called chiasmata. Prophase I has been divided into a series of sub-stages which are named according to the appearance of chromosomes.

(a) Leptotene:

1) Formation of homologous chromosomes occurs.
2) Each chromosome is attached to nuclear envelope by its both ends.
3) Centrosome or centrioles pairs, separate and development astral rays occurs.

(b) Zygotene:

1) The process of attachment or pairing of homologous chromosomes is called synapsis. Synapsis produces pairs of chromosomes called bivalents.
2) The nucleoprotein complex that helps in adherence of sister chromatids and then homologous chromosomes is called **synaptonemal complex**.
3) Asters continue to move away from each other.

(c) Pachytene:

1) It is one of the most important stages/ sub-stage of meiosis as chromosome thickening and crossing over takes place in this sub-stage.
2) Each bivalent at the end of Zygotene is made up of two homologous chromosomes and each chromosome comprises of two chromatids.
3) The two chromatids of the same chromosome are called sister chromatids while chromatids belonging to different chromosomes of the homologous pair are known as non-sister chromatids.
4) Crossing over (exchange of chromatid segments or genetic material between the homologous chromosomes) always occurs between non-sister chromatids.

(d) Diplotene:

1) Separation of homologous chromosomes occurs except in the region of chiasmata.

2) In oocytes of many fishes, amphibians, reptiles and birds the bivalents elongate and become converted into lampbrush chromosomes.

(e) Diakinesis:

1) Chromosomes condense further during the Diakinesis stage.
2) This is the first point in meiosis where the four parts of the tetrads are actually visible. Reduction in number of chiasmata is observed.
3) In this last stage of the first meiotic prophase the chromosomes are shortest and thickest.
4) In each pair the chromatids of a chromosome remain attached in the region of centromere. The chromosomes bivalents move towards the periphery of the nucleus and remain connected only at the points of chiasmata.
5) Chiasmata slip from their original position and pass outwardly. The phenomenon is called terminalization.
6) In case of animal cells, asters reach the opposite sides in position of poles.
7) The chromosomes are finally released into the cytoplasm.

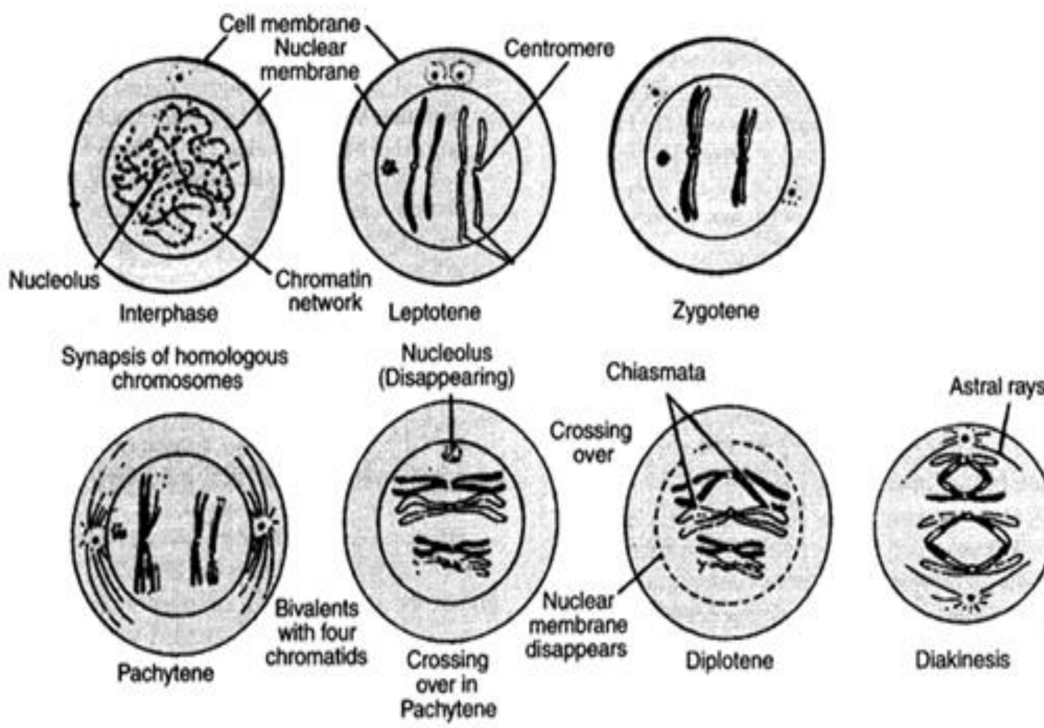


Fig. 9.12: Different stages of Prophase I of meiosis I

2. Metaphase I: Two major events of metaphase I include complete disintegration of nuclear membrane and the formation of spindle. All the chromosomes, each along with their two chromatids, move to the equatorial region of the newly formed spindle.

Differing from the metaphase stage of mitosis, the centromeres of chromosome pairs in metaphase stage of meiosis I become attached with the spindle fibres near the equatorial region.

The centromeres remain clearly apart from each other and face the opposite poles while the arms of the chromosome pairs lie towards the equator.

1) Nuclear envelop degenerate and spindle fibres appear.
2) At this stage, bivalents get arranged on the equator.
3) Chromosomes occur in bivalents having chiasmata.
4) Chromosomes of a bivalent get attached to spindle fibre belonging to different poles.

3. Anaphase I: There is first a repulsion and then movement of the two centromeres of the homologous chromosomes towards the opposite poles of the spindle in anaphase-I. A centromere carries either a paternal or a maternal chromosome to one pole but not both the chromosomes. This actually reduces the chromosome number from diploid (2n) to haploid (n), which is the main feature of meiosis of reduction division.

1) Homologous chromosomes separate and move to opposite poles due to disintegration of chiasmata.
2) This results in formation of two haploid sets of chromosomes.
3) Separation of homologous chromosomes is known as disjunction, separated chromosomes are called univalent.
4) At the end of anaphase-I, two groups of chromosomes are formed, with half number of chromosome present in the mother cell.

4. Telophase I: A nuclear membrane develops around each group of homologous chromosomes present on the two opposite poles in the form of a compact group in Telophase-I. The nucleolus reappears. Both the so formed daughter nuclei contain haploid number (n) of chromosomes, and each chromosome contains a pair of chromatids.

Both the daughter nuclei may or may not be separated by a plasma membrane and soon pass on to the next division, i.e., meiosis division-II.

Meiosis II: It is the second meiotic division, and usually involves equational segregation, or separation of sister chromatids. Mechanically, the process is similar to mitosis, though its genetic results are fundamentally different. The end result is production of four haploid cells (n chromosomes, 23 in humans) from the two haploid cells (with n chromosomes, each consisting of two sister chromatids) produced in meiosis I. The four main steps of meiosis II are: Prophase II, Metaphase II, Anaphase II, and Telophase II.

1. Prophase II: The chromosomes separate into chromatids in both the haploid nuclei and cells formed after meiosis division-I. The separated chromatids remain connected only at the centromeres. The chromosomes start coiling and become shorter and thicker. The nuclear membrane and nucleolus start disintegrating and some spindle fibres also start appearing.

1) It is simple and of short duration.
2) Shortening of chromosomes occur.
3) Nucleolus disappears and nuclear envelope degenerate.

4) In animal cells, centrosomes develop astral rays and move to the opposite sides.

2. Metaphase II:

The chromosomes get arranged in an equatorial position in the newly-formed spindle. Very soon, the chromosome pair separates, of which each contains its own centromere. This is a very short phase of meiosis division-II.

1) Chromosome gets attached to spindle fibres, one from each pole.
2) Area of chromosome to which spindle fibres attach is called kinetochore.
3) Chromosomal fibres contract and bring the chromosomes get arranged on the equator.
4) The limbs of the two chromatids are divergent.

3. Anaphase II:

In this phase, the two sister chromosomes of each pair start to move towards the opposite poles of the spindle. They are being drawn towards the opposite poles by their centromeres.

1) Separation of centromere of two chromatids occurs.
2) The separated chromatids become daughter chromosomes.
3) Chromosomes move to opposite poles.
4) At the end of anaphase II, each pole has haploid number of chromosomes.

4. Telophase II:

Each polar group of chromosomes gets enveloped by a nuclear membrane, and there is the reappearance of nucleolus. Four cells are formed by cytokinesis, and the nucleuses in all these so formed four young cells contain haploid number (n) of chromosomes. In this way, four haploid cells are resulted from a single diploid cell in the process of meiosis.

1) De-condensation of chromosomes occurs.
2) Chromosomes organize to reform a nucleus, along with formation of nucleolus and nuclear envelope.
3) Astral rays and spindle fibres disappear.

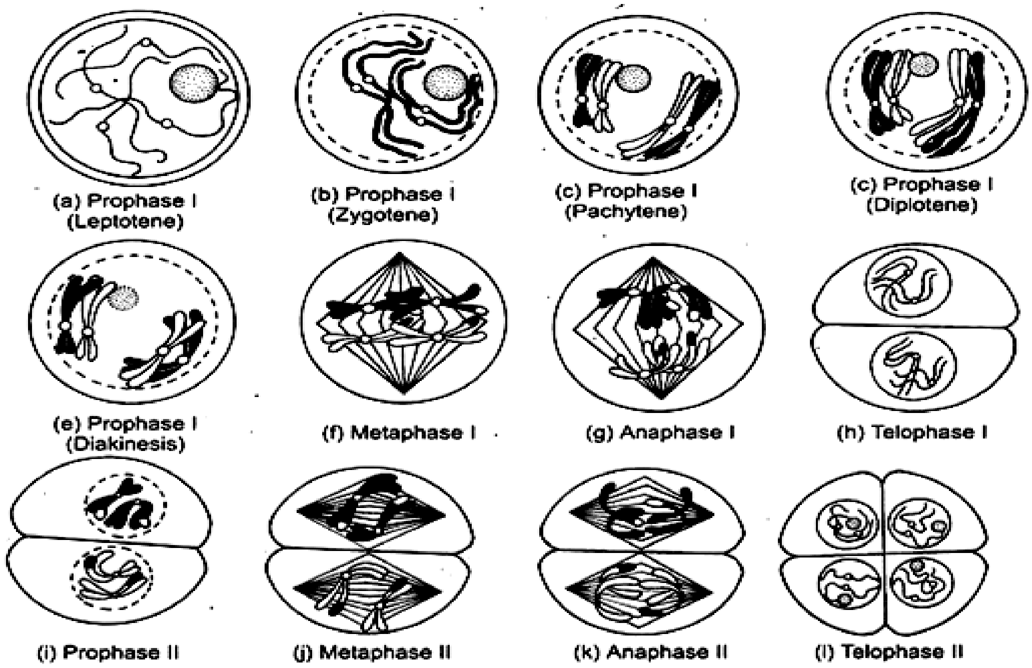


Fig. 9.13: Different stages of meiosis

Table-3: Differences between meiosis I and meiosis II

S.No.	Meiosis I	Meiosis II
1	It is heterotypic or reductional division.	It is homotypic or equational division.
2	It is a complex process and takes long duration of time.	It is a simple process and takes short duration of time.
3	There is present both growth phase and synthetic phase before interphase.	Only growth phase is present before interphase (called interkinesis). Synthetic phase is absent.
4	Sister chromatids have convergent arms in prophase-I	Sister chromatids have divergent arms in prophase-II
5	Crossing over occurs in prophase-I	No crossing over occurs in meiosis-II

Mitosis and meiosis are similar processes in that they both result in the separation of existing cells into new ones. They differ, however, in their specific processes as well as in their products. The reason for these differences lies in the difference in the class of cells that each process creates. Mitosis is responsible for reproducing somatic cells and meiosis is responsible for reproducing germ cells. In single-cell organisms, mitosis is the only form of cellular reproduction. One round of mitosis yields two genetically identical cells. In bacteria, this process results in an entirely new, independent organism. This is classified as asexual reproduction because it does not require sex for the creation of new organisms.

In multicellular organisms, like us, mitosis only occurs in somatic cells, which comprise all cells in an organism excluding germ cells. Cells that undergo mitosis duplicate their chromosomes, resulting in cells with two times their normal haploid or diploid numbers (4N chromosomes). Newly synthesized chromosomes remain closely associated with their like-chromosome. These two identical chromosomes are called sister chromatids. Once, the duplicated sisters' chromatids are separate such that one copy of each chromosome lines up on opposite ends of the cell. The cell then pinches in the center until it breaks into two different cells. A nucleus then forms around the chromosomes in each cell to yield two cells with the same original number of chromosomes as the preexisting cell.

There are two major differences between mitosis and meiosis. First, meiosis involves not one, but **two** cell divisions. Second, meiosis leads to the production of germ cells, which give rise to gametes. In meiosis, as in mitosis, the maternal and paternal homologues are replicated during DNA replication yielding two pairs of sister chromatids. After the first cell division, each of the resulting cells contains a pair of sister chromatids; one maternal pair and the other paternal. Unlike mitosis, meiosis does not end after one division; it continues with a second cell division. In this division, the sister chromatids are separated yielding four total haploid cells.

Table-4: Differences between mitosis and meiosis

S.No.	Mitosis	Meiosis
1	The division occurs in somatic cells and it is a single division.	It occurs in reproductive cells and it is a double division.
2	Mitosis takes place throughout the life of a multicellular organism.	Meiosis takes place only at the time of sexual reproduction.
3	The daughter cells resemble each other as well as their mother cell.	The daughter cells neither resemble one another nor their mother cell.
4	Chromosome number remains the same.	Chromosome number is halved.
5	Mitosis is required for growth, repair and healing. It does not introduce variations.	Meiosis has no such function. It introduces variations.
6	It occurs in both sexually and asexually reproducing organism.	Meiosis is found in only sexually reproducing organism.
7	Prophase: is shorter duration, generally of a few hours. Crossing over does not occur.	Prophase-I is longer duration, which may be of several days. Crossing over occurs.
8	Metaphase: Chromosomes are replicated but unpaired.	Chromosomes are replicated as well as paired to form bivalents.
9	Anaphase: Chromosomes are single stranded.	Chromosomes are double stranded in anaphase I and single stranded in anaphase-II.

10	Telophase: It is an essential component of mitosis	Telophase I may be absent. Telophase II always occurs.

9.6.2.1 Significance of Meiosis

In the process of sexual reproduction, the male and female gametes fuse to form a zygote which gives rise to the new off-springs. If the gametes contained the same number of chromosomes as that of their parents, the off-springs would have an ever-increasing chromosomes number in all future generations to come, and this might have resulted always in the formation of new and peculiar types of off-springs, much different from that of their parents. To solve this problem, nature has provided the phenomenon of meiosis to all sexually reproducing plants and animals. Meiosis maintains the haploid nature of gametes.

Another fascinating aspect of meiosis is that, it begins at the very early life in the individual but remains arrested for a considerably long time in the prophase state. In males the completion depends upon the attainment of sexual maturity. In the female, the completion of the division comes only shortly before or after fertilization. The process of meiosis not only reduces the chromosome number to half for the purpose of reproduction but also by random distribution of paternal and maternal chromosomes and by crossing-over through chiasma, it produces gametes, none of which are exactly alike. Thus, a large number of variations result, which have got great significance in evolution.

1. DNA, the sole hereditary material, is distributed equally among the gametes by the process of meiosis.
2. It provides stimulus for the formation of gemmates and spores.
3. Meiosis causes conversion from sporophytic generation to gametophytic generation in plants. It forms spores (n) from the spore mother cells (2n) and thus maintains the alternation of generations in organisms.
4. Meiosis-I reduce the number of chromosomes to one half or single genome where each chromosome is without its homologue.
5. The products of meiosis-I posses replicated or dyad chromosomes. Occurrence of dyad chromosome acts as a stimulus for meiosis-II to occur.
6. Meiosis causes segregation and random assortment of genes. Random assortment of paternal and maternal chromosomes produces genetic variations.
7. Crossing over brings about gene recombination or new combination of genes. It also produces genetic variation within the species. The variations are important raw materials for evolution and also help in improvement of races.
8. Non-disjunction and breakage of chromosomes may occur during anaphase-I due to non - dissolution of chiasmata. It produces chromosomal aberrations, aneuploidy and polyploidy.
9. Meiosis essentially maintains constancy in chromosomes from generation to generation.
10. It leads to the formation of haploid gametes (n) which is an essential process in sexually reproducing organisms. Fertilization restores the normal somatic (2n) chromosome number.

9.7 STRUCTURE & COMPOSITION OF NUCLEIC ACIDS

Cells are known to contain many biomolecules such as proteins, lipids, carbohydrates and nucleic acids. Among these, nucleic acids are large and heavy biomolecules which have molecular weight from 30,000 to several millions. The large size of nucleic acids is because they are made up of millions of monomeric units. **Friedrich Miescher** (1869, Swiss physician and biologist) first of all isolated nucleic acid from pus cells. They were then named as ***nuclein***. Oscar Hertwig (1884, German zoologist and professor) proposed this nuclein to be the carrier of hereditary traits. Because of their acidic nature they were initially called as **nucleonic acid** which were later named as nucleic acid. Nucleic acids are found to be present in all living organisms' plants, animals, and bacteria and even in viruses.

There are two types of nucleic acid found to be present in living cells **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid). In eukaryotes DNA is present in membrane bound cell organelle called as nucleus, whereas, in prokaryotes DNA is present (single chromosome) free in cytoplasm. Such DNA found in bacterial cell is known as **nucleoid**. DNA is the genetic material of almost all living organisms except some viruses, which have RNA as their genetic material. DNA is basically made up of three components phosphoric acid, deoxyribose sugar and nitrogenous bases (purines and pyrimidines). Presence of purine and pyrimidines in nucleic acid was reported by Fisher (1880s) and Levene (1910) reported phosphoric acid and deoxyribose sugar to be present in DNA.

In eukaryotes, along with nucleus DNA is also present in cell organelles such as, mitochondria and chloroplast. Such DNA is known as **extra chromosomal** or **extra nuclear DNA**. In nucleus, DNA is present in form of chromosomes i.e. it is linear however; extra chromosomal DNA (present in mitochondria or chloroplast) is always circular. Beside nucleoid, prokaryotes also contain extra chromosomal DNA present in form of circular plasmids. Although, DNA present in prokaryotes and eukaryotes are similar in chemical components by which they are made and the function they perform (both serve as genetic material), there exists several differences between prokaryotic and eukaryotic DNA which are as follows:

9.8 DNA

Deoxyribonucleic acid (DNA) is a molecule composed of two chains (made of nucleotides) which coil around each other to form a double helix carrying the genetic instructions used in the growth, development, functioning and reproduction of all known living organisms and many viruses. DNA and ribonucleic acid (RNA) are nucleic acids; alongside proteins, lipids and complex carbohydrates (polysaccharides), nucleic acids are one of the four major types of macromolecules that are essential for all known forms of life.

9.8.1 Components of DNA

There are three components, a pentose sugar, phosphoric acid and nitrogenous bases which combine to form monomer unit called as nucleotide. Large number of nucleotides joins to form polynucleotide chain. Each nucleotide is composed of one of four nitrogen-containing nucleobases i.e., cytosine (C), guanine (G), adenine (A) or thymine (T), a sugar called deoxyribose, and a phosphate group. The nucleotides are joined to one another in a chain by covalent bonds between the sugar of one nucleotide and the phosphate of the next, resulting in an alternating sugar-phosphate backbone. The nitrogenous bases of the two separate polynucleotide strands are bound together, according to base pairing rules (A with T and C with G), with hydrogen bonds to make double-stranded DNA.

The three components of DNA are:

(1) Sugar:

The sugar present in DNA is a pentose sugar (Fig. 5.2) called as deoxyribose sugar. Its name indicates that it is derived from ribose sugar by loss of an oxygen atom.

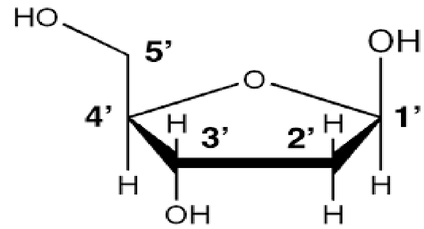


Fig.9.14. Structure of deoxyribose sugar

Deoxyribose sugar joins with a nitrogenous base to form nucleoside.

(2) Phosphoric acid

Phosphoric acid along with sugar molecule forms the backbone of polynucleotide chain. The bond formed by a phosphate between the sugar molecules of two different nucleotides is called phosphodiester bond. In one strand of DNA helix the phosphodiester bond is formed in the direction 3ˈ-5ˈ direction and in the other strand of the helix phosphodiester bonds are formed in 5ˈ-3ˈ direction.

(3) Nitrogenous bases

There are four nitrogenous bases present in structure of DNA which are grouped into two classes called as purines and pyrimidines. The complementary nitrogenous bases are divided into two groups, pyrimidines and purines. In DNA, the pyrimidines are thymine and cytosine; the purines are adenine and guanine.

Pyrimidines

Pyrimidines are simple aromatic compounds composed of carbon and nitrogen atoms in a six-membered, heterocyclic ring system. The name also refers to a specific compound (composition $C_4H_4N_2$), not found in nature that can be regarded as the parental structure of a wide range of naturally occurring chemical species. The most abundant naturally occurring pyrimidines are uracil (2, 4-dihydroxypyrimidine), cytosine (2-hydroxy-4-aminopyrimidine), and thymine (2, 4-dihydroxy-5-methyl pyrimidine). The first two are found predominantly in RNA, while the latter two are found predominantly in DNA. Small amounts of thymine are found in transfer RNA. The two pyrimidines found in DNA are usually base-paired with a purine residue on the complementary strand, so the purine to pyrimidine ratio in DNA is unity. In RNA, which is single-stranded, this ratio varies widely.

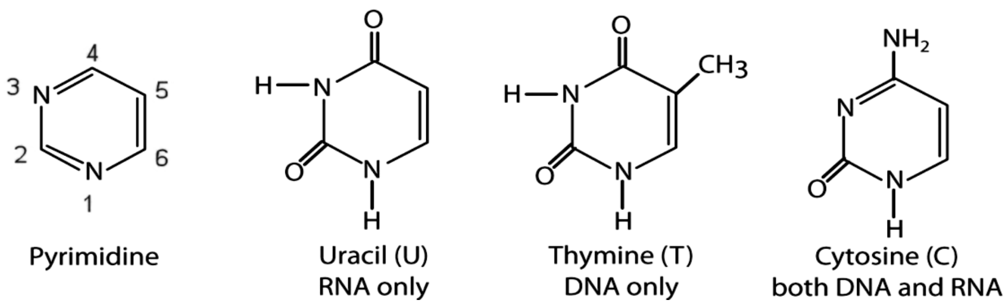


Fig. 9.15 - Structure of Nitrogenous base (Pyrimidines)

The term pyrimidine is also used to refer to pyrimidine derivatives, most notably the three nitrogenous bases that, along with the two purines, are the building blocks of both deoxyribonucleic acids (DNA) and ribonucleic acid (RNA). The pyrimidine nitrogenous bases are derived from the organic compound pyrimidine through the addition of various functional groups. Each pyrimidine ring has 2 nitrogen atoms present at first and third position and 4 carbon atoms present at 2^{nd}, 4^{th}, 5^{th} and 6^{th} position of pyrimidine ring. In all three pyrimidines C-2 is linked to oxygen by double bond.

Purines

A purine is a heterocyclic aromatic organic compound that consists of a pyrimidine ring fused to an **imidazole ring**. Purine gives its name to the wider class of molecules, *purines*, which include substituted purines and their tautomers, are the most widely occurring nitrogen-containing heterocycle in nature. Purine is water soluble, are found in high concentration in meat and meat products, especially internal organs such as liver and kidney.

All purines contain a double-ringed structure that consists of a six-membered ring fused to a five-membered ring; think of a honeycomb cell attached to a pentagon. The purine ring is considered a heterocyclic molecule, meaning it is a closed ring containing at least two different kinds of atoms. Each of purines rings contains two nitrogen atoms, for a total of four within the double-ringed structure. These nitrogen atoms are located in the same positions in all purines.

The remaining five positions within the rings are occupied by carbon atoms. The purine ring is encircled by hydrogen atoms, which can be replaced by other atoms or groups of atoms to form different purines.

Fig. 9.16 Structure of Nitrogenous base (Purines)

Purines are double ringed nitrogenous bases found to be present in nucleic acids. Both DNA and RNA contain two types of purines which are adenine and guanine. Carbon atoms in purine ring are numbered in anti-clock wise direction and carbon atoms in imidazole ring are numbered in clockwise direction. C-4 and C-5 are common to both the rings. The four nitrogen atoms are present at 1^{st}, 3^{rd}, 7^{th} and 9^{th} position.

Nucleoside

Nucleoside is a molecule formed by association of nitrogenous base and pentose sugar. Nitrogenous bases get attached to C-1 of pentose sugar. When a glycosidic bond is formed between sugar and nitrogenous base, C-1 of sugar is always involved. If the nitrogenous base is a purine, the nitrogenous base is linked to the sugar via its N-9 atom, while if it's a pyrimidine, it is linked via its N-1 atom. Depending upon the type of sugar present, nucleosides are of two types; Ribonucleosides and Deoxyribonucleosides. Because the pentose sugar present in DNA is deoxyribose, hence, nucleoside present in DNA called **Deoxyribonucleosides**.

There are four types of deoxyribose nucleosides present in DNA molecule:

1. Deoxyadenosine = Adenine + Deoxyribose
2. Deoxyguanosine = Guanine + Deoxyribose
3. Deoxycytidine = Cytosine + Deoxyribose
4. Deoxythymidine = Thymine + Deoxyribose

Nucleotide

Nucleotides are monomers which get linked to one another to form a polynucleotide chain present in DNA molecule. Nucleotides are the building blocks of nucleic acids; they are composed of three subunit molecules: a nitrogenous base, a five-carbon sugar (ribose or deoxyribose), and at least one phosphate group. Nucleotide is formed by addition of phosphoric acid to nucleoside. Hence it can be said that a nucleotide is **nucleoside monophosphate**.

Chargaff's Rule

Erwin Chargaff (1950), an Austro-Hungarian biochemist, made observations on the bases and other components of DNA. These observations or generalizations are **called as Chargaff's base equivalence rule**.

1. Purine and pyrimidine base pairs are in equal amount, i.e., adenine + guanine = thymine + cytosine. [A + G] = [T + C], also, [A+G] / [T+C] = 1
2. Molar amount of adenine is always equal to the molar amount of thymine. Similarly, molar concentration of guanine is equaled by molar concentration of cytosine.
   [A] = [T], i.e., [A] / [T] = 1; and [G] = [C], i.e., [G] / [C] = 1
3. Sugar deoxyribose and phosphate occur in equimolar proportions.
4. A-T base pairs are rarely equal to C-G base pairs.
5. The ratio of [A+T] / [G+C] is variable but constant for a species. It can be used to identify the source of DNA. The ratio is low in primitive organisms and higher in advanced ones.

9.8.2 Structure of DNA

Watson and crick model

In 1953, **James D. Watson** (American molecular biologist, geneticist and zoologist) and **Francis H.C. Crick** (British molecular biologist, biophysicist, and neuroscientist), studied physical and chemical properties of DNA and proposed a three dimensional helix model of physiological DNA (i.e. B-DNA), which is made up of two strands that are twisted around each other to form a right-handed helix. The model is commonly called as "Watson and crick model". The model is based upon X-ray Crystallographic analysis, obtained by two scientists, **Rosalind Franklin** and **Maurice Wilkins**.

The two DNA strands are anti-parallel, such that the 3′ end of one strand faces the 5′ end of the other (5.3.2). The 3′ end of each strand has a free hydroxyl group, while the 5′ end of each strand has a free phosphate group. The sugar and phosphate of the polymerized nucleotides form the backbone of the structure, whereas the nitrogenous bases are stacked inside. These nitrogenous bases on the interior of the molecule interact with each other, base pairing.

Analysis of the diffraction patterns of DNA has determined that there are approximately 10 bases per turn in DNA. The asymmetrical spacing of the sugar-phosphate backbones generates major grooves (where the backbone is far apart) and minor grooves (where the backbone is close together). These grooves are locations where proteins can bind to DNA. The binding of these proteins can alter the structure of DNA, regulate replication, or regulate transcription of DNA into RNA.

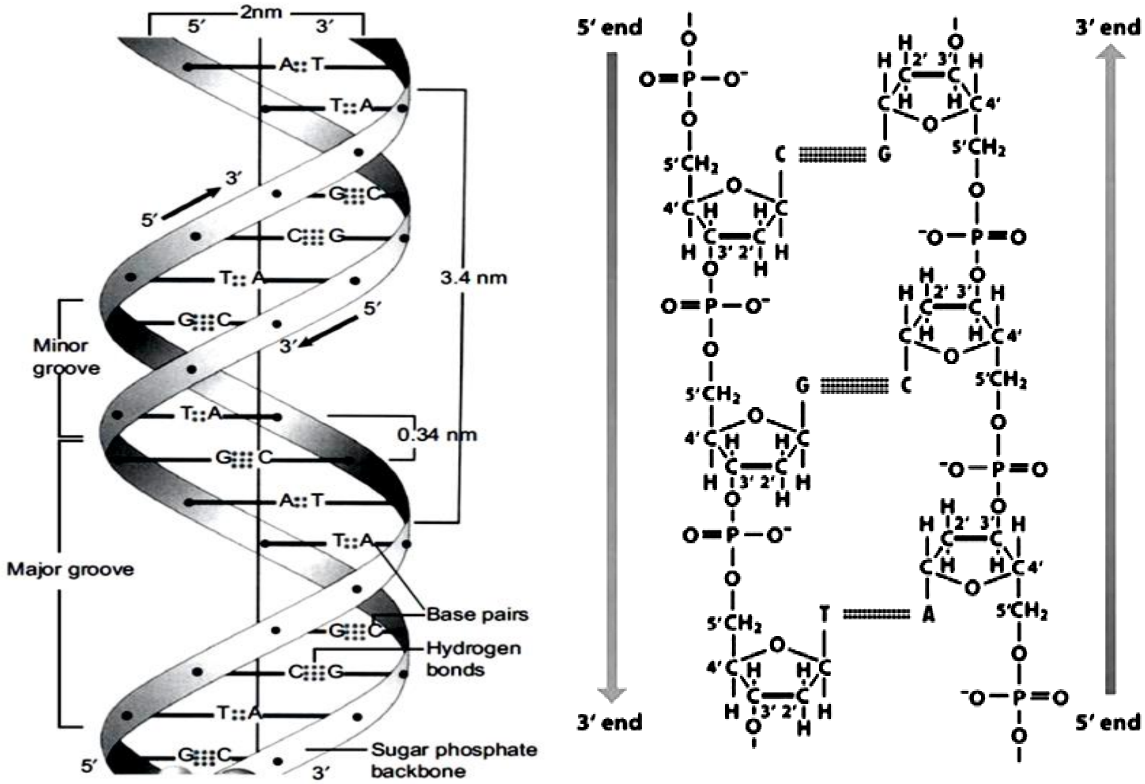


Fig. 9.17 Watson Crick's double helical structure of DNA molecule

9.9 RNA (RIBONUCLEIC ACID)

Ribonucleic acid (RNA) is typically single stranded and is made of ribonucleotides that are linked by phosphodiester bonds. A ribonucleotide in the RNA chain contains ribose (the pentose sugar), one of the four nitrogenous bases (A, U, G, and C), and a phosphate group. The subtle structural difference between the sugars gives DNA added stability, making DNA more suitable for storage of genetic information, whereas the relative instability of RNA makes it more suitable for its more short-term functions. The key difference in RNA structure is that the ribose sugar in RNA has a hydroxyl (-OH) group which is absent in DNA. RNA plays a very crucial role in the gene expression pathway by which genetic information in DNA is coded into proteins that determine cell function. The RNA-specific pyrimidine uracil forms a complementary base pair with adenine and is used instead of the thymine used in DNA. Even though RNA is single stranded, most types of RNA molecules show extensive intramolecular base pairing between complementary sequences within the RNA strand, creating a predictable three-dimensional structure essential for their function.

RNA is a polymeric molecule, essential in various biological roles in coding, decoding, regulation, and expression of genes. RNA and DNA are nucleic acids, and, along with lipids, proteins and carbohydrates constitute the four major macromolecules essential for all known forms of life. Like DNA, RNA is assembled as a chain of nucleotides, but unlike DNA it is more often found in nature as a single-strand folded onto itself, rather than a paired double-strand. Cellular organisms use messenger RNA (mRNA) to convey genetic information (using the nitrogenous bases of guanine, uracil, adenine, and cytosine, denoted by the letters G, U, A, and C) that directs synthesis of specific proteins. Many viruses encode their genetic information using an RNA genome.

Some RNA molecules play an active role within cells by catalyzing biological reactions, controlling gene expression, or sensing and communicating responses to cellular signals. One of these active processes is protein synthesis, a universal function where RNA molecules direct the assembly of proteins on ribosomes. This process uses transfer RNA (tRNA) molecules to deliver amino acids to the ribosome, where ribosomal RNA (rRNA) then links amino acids together to form proteins.

Messenger RNA (mRNA) is the RNA that carries information from DNA to the ribosome, the sites of protein synthesis (translation) in the cell. The coding sequence of the mRNA determines the amino acid sequence in the protein that is produced. Many RNAs do not code for protein, however about 97% of the transcriptional output is non-protein-coding in eukaryotes). These so-called non-coding RNAs ("ncRNA"), can be encoded by their own genes (RNA genes), but can also derive from mRNA introns. The most prominent examples of non-coding RNAs are transfer RNA (tRNA) and ribosomal RNA (rRNA), both of which are involved in the process of translation. There are also non-coding RNAs involved in gene regulation, RNA processing and other roles. Certain RNAs are able to catalyse chemical reactions such as cutting and ligating other RNA molecules, and the catalysis of peptide bond formation in the ribosome, known as ribozymes.

9.9.1 Structure and composition of RNA

RNA is one of the three major macromolecules (along with DNA and proteins) that are essential for all known forms of life. The chemical structure of RNA is very similar to that of DNA, with two differences i.e., RNA contains the sugar ribose while DNA contains the slightly different sugar deoxyribose (a type of ribose that lacks one oxygen atom), and RNA has the nucleobase uracil, while DNA contains thymine (uracil and thymine have similar base-pairing properties). RNA, like deoxyribonucleic acid (DNA), is composed of nucleic acids that are found in the nucleus of plants and animals. Nucleic acids consist of high molecular weight macromolecules, which are made up of hundreds or thousands of smaller single unit molecules called nucleotides, all bound together. These molecules are the storehouse and delivery system of genetic traits and represent an organism's instruction manual for its protein–comprised manufacturing system. RNA, unlike DNA, is also found in other parts of the cell other than the nucleus.

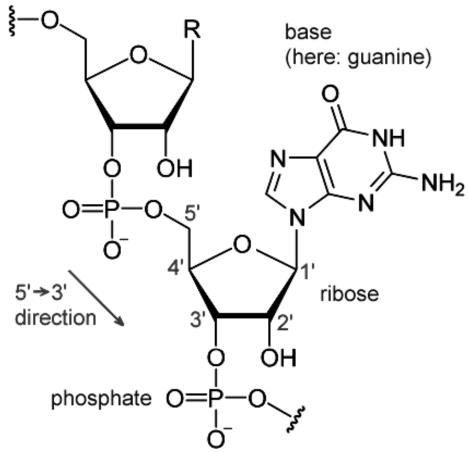


Fig.9.18 Chemical structure of RNA

In fact, the majority of the RNA is present in the cytoplasm in various forms. Nuclear RNA is comprised of single stranded sequences and has a lower molecular weight than DNA.

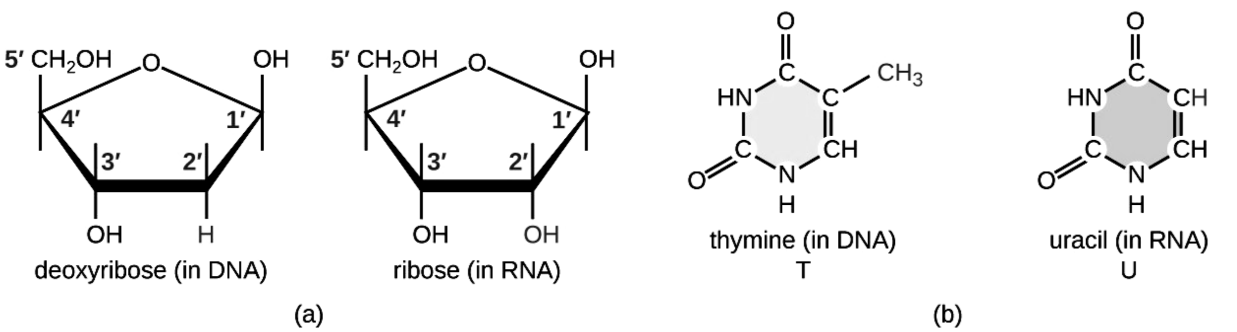


Fig.9.19: (a) Ribonucleotides contain the pentose sugar ribose instead of the deoxyribose found in deoxy-ribonucleotides; (b) RNA contains the pyrimidine-uracil in place of thymine found in DNA.

Each nucleotide molecule consists of a sugar group, a phosphate group, and an amino (nitrogen containing) group. The main difference between RNA and DNA is that in RNA the sugar is ribose (a five carbon sugar); while in DNA the sugar is deoxyribose. The prefix deoxy means that one oxygen atom is missing from the ribose. RNA is built from the same nucleotides as DNA just as proteins are built up from amino acids. There are only four bases that makeup RNA: adenine, cytosine, guanine, and uracil (A, C, G, and U, respectively). DNA contains thymine (T) instead of U. Structurally; the backbone consists of alternating sugar and phosphate parts, while the amino groups stick out like branches from the backbone. This coiled backbone in RNA if stretched out, would resemble a stretched out slinky.

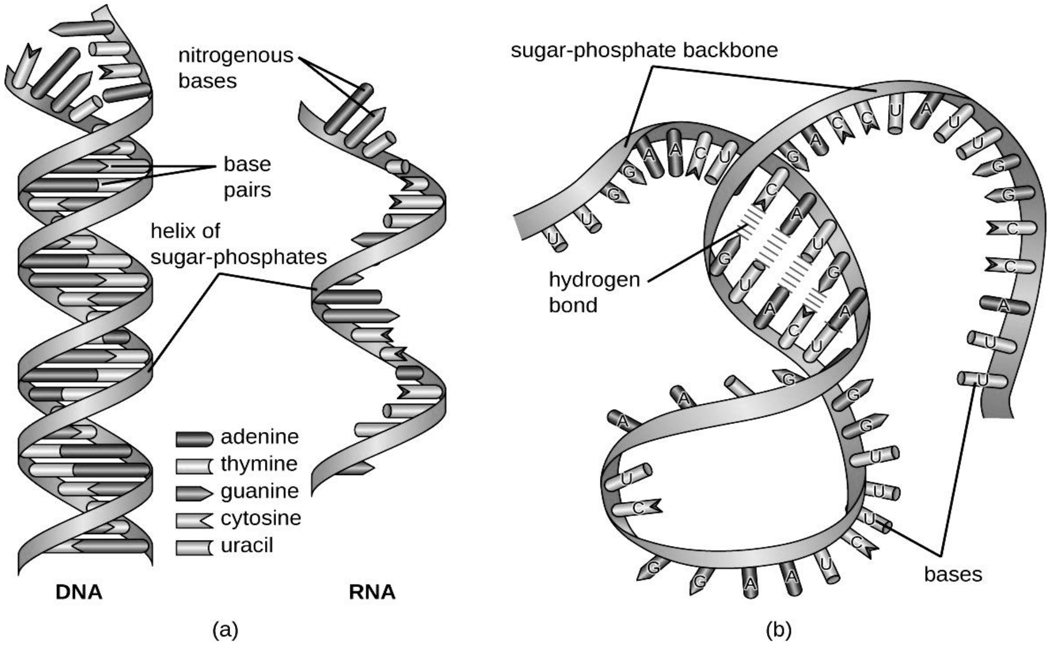


Fig.9.20: (a) DNA is typically double stranded, whereas RNA is typically single stranded. (b) Although it is single stranded, RNA can fold upon itself, with the folds stabilized by short areas of complementary base pairing within the molecule, forming a three-dimensional structure.

Ribonucleic acid (RNA) is a polymer, made up of large number of nucleotides. A structure called nucleoside, formed by joining of sugar molecules with a nitrogenous base. Now when a phosphate group is added to nucleoside it becomes a nucleotide **Fig.9.21** Nucleotides of RNA are also known as ribonucleotides. In RNA molecules one nucleotide is linked to another nucleotide by 3ˈ-5ˈ phosphodiester bond. Large number of nucleotides gets linked to form single stranded unbranched polynucleotide RNA chain**.** Each nucleotide is made up of three subunits which are ribose sugar, phosphate and nitrogenous base. **Fig.9.21** shows how nucleotides are linked to form RNA.

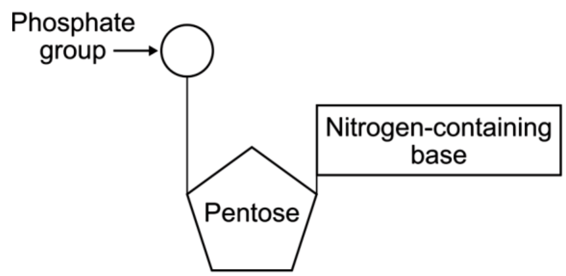


Fig.9.21 Structure of single nucleotide

Sugar present in RNA is ribose sugar. It is identical in structure to deoxyribose sugar present in DNA with only one difference that in ribose sugar an OH group is present at carbon number 2 whereas in deoxyribose sugar carbon number 2 contains H atom. Other than this structure of both the sugars (ribose and deoxyribose) is same. Both are pentose sugar with 5 carbon atom (carbon number 1′ to 5′), out of which four carbon atoms with an oxygen atom forms a five-member ring and the fifth carbon is present outside the ring as a part of CH_2 group.

A base (adenine, guanine, cytosine or thymine) is attached to carbon number 1 of each ribose sugar. A phosphate group functions to join two nucleotides together as one phosphate is linked to carbon number 3 of one ribose sugar and carbon number 5 of another ribose sugar. There are four nitrogenous bases found in RNA, two purines and two pyrimidines. Pyrimidines are single ringed nitrogen compound in which N atom is present at position 1 and 3 of six-membered ring. Uracil and cytosine are the two pyrimidines present in RNA. Purines are double ringed nitrogen compounds in which a five-membered imidazole ring is linked to pyrimidine ring. Adenine and guanine are the two purines present in RNA.

DNA is universal genetic material found to be present in almost all living organisms except plant viruses, some animal virus and several bacteriophages which have RNA as their genetic material (Table-2). When, RNA is present as genetic material, mostly it is single stranded but in some cases it can be double stranded. When, RNA is present in double stranded form, pairing between complementary bases occurs in the same way as it occurs in DNA i.e., Adenine pairs with Uracil and Guanine pairs with Cytosine.

Table-2: Viruses with RNA as genetic material

Type of Virus	Type of RNA	Example
Plant Virus	Single stranded Double stranded	Tobacco mosaic virus Wound tumour
Animal Virus	Single Stranded Double Stranded	Influenza Virus Reo virus
Bacteriophage	Single Stranded	MS2, F2

9.9.2 Types of RNA

The three major types of RNAs with their respective cellular composition are given below:

1. Ribosomal RNA (rRNA): 50-80%
2. Messenger RNA (mRNA): 5-10%
3. Transfer RNA (tRNA): 10-20%

Besides the three RNAs referred above, other RNAs are also present in the cells. These include heterogeneous nuclear RNA (hnRNA), small nuclear RNA (snRNA), small nucleolar RNA (snoRNA) and small cytoplasmic RNA (scRNA).

9.10 GENETIC CODE

The genetic code is the set of rules by which information encoded in genetic material (DNA or RNA sequences) is translated into proteins (amino acid sequences) by living cells. The genetic code, once thought to be identical in all forms of life, has been found to diverge slightly in certain organisms and in the mitochondria of some eukaryotes. Nevertheless, these differences are rare, and the genetic code is identical in almost all species, with the same codons specifying the same amino acids.

The genetic code consists of 64 triplets of nucleotides. These triplets are called codons. With three exceptions, each codon encodes for one of the 20 amino acids used in the synthesis of proteins. This produces some redundancy in the code; most of the amino acids being encoded by more than one codon.

9.10.1 Types of Codon

(a) Sense Codon: Those codons that code for amino acids are called sense codons. There are 61 sense codons in the genetic code which code for 20 amino acids.

(b) Signal Codons: Those codons that code for signals during protein synthesis are known as signal codons. There are four codons which code for signal. These are AUG, UAA, UAG and UGA.

Signal codons are of two types:

1. Start codons, and
2. Stop codons.

1. Start Codon (Chain Initiation Codons): Codon with nucleotide sequence "AUG" is called as start codon. It codes for amino acid methionine in most organisms. The process of translation (protein synthesis) always begins with expression of start codon AUG.

However, codon AUG can occur later in mRNA also, then it will simply code for amino acid methionine. The triplets AUG and GUG, plays double roles in E. coli. When they occur in between the two ends of a cistron (intermediate position), they code for the amino acids methionine and valine, respectively in an intermediate position in the protein molecule.

2. Stop Codon (Chain Termination Codons): Out of total 64 genetic codes, the 3 triplets UAA, UAG, UGA do not code for any amino acid. They were originally described as non-sense codons, as against the remaining 61 codons, which are termed as sense codons. During the process of protein Synthesis these codons function to terminate the process.

When any of the three codon is read, the ribosomes pauses and gets separated from mRNA and hence the process of protein synthesis is terminated. Due to this reason these codons are also called as termination codons. UAA, UAG and UGA are also known as ochre, Amber and Umber respectively, are believed to be used as signals which end the synthesis of a protein chain.

9.11 PROTEIN SYNTHESIS

Biosynthesis of protein is under direct control of DNA in most cases or else under the control of genetic RNA where DNA is absent. Information for structure, of a polypeptide is stored in a polynucleotide chain. In 1958 **Crick** proposed that the information present in DNA (in the form of base sequence) is transferred to RNA and then from RNA it is transferred to protein (in the form of amino acid sequence), and that this information does not flow in the reverse direction, that is, from protein to RNA to DNA.

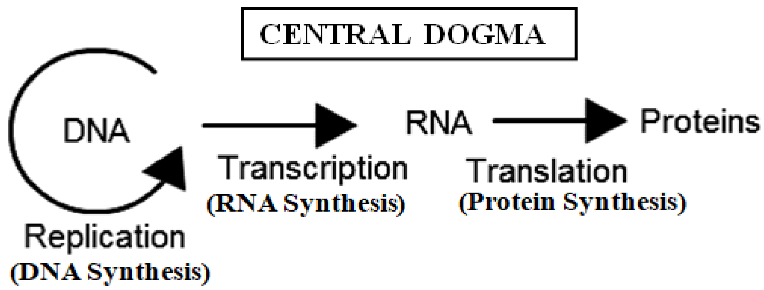


Fig. 9.22 Central Dogma of living cell

DNA molecules provide the information for their own replication. This relationship between DNA, RNA and protein molecules is known as **Central Dogma**. Temin (1970) reported that retroviruses operate a central dogma reverse (inverse flow of information) or feminism inside host cells. Genomic RNA of these viruses first synthesizes DNA through reverse transcription; this process is catalyzed by the enzyme reverse transcriptase, DNA then transfers information to messenger RNA which takes part in translation of the coded information to form polypeptide. Every living cell follows a process of central dogma, which ultimately leads to synthesis of protein.

9.11.1 Mechanism of Protein Synthesis

The synthesis of proteins takes two major steps; **(1) transcription**, involving transfer of genetic information from DNA to mRNA, which heads out of the cell's nucleus and into the cytoplasm, and **(2) translation**, involving translation of the language of nucleic acid into that of proteins. During translation, the mRNA works with a ribosome and tRNA to synthesize proteins.

(1) Transcription It is one of the first processes in the mechanism of protein synthesis. In transcription, a complementary strand of mRNA is synthesized according to the nitrogenous base code of DNA. The first step in transcription is the partial unwinding of the DNA molecule so that the portion of DNA that codes for the needed protein can be transcribed. Once the DNA molecule is unwound at the correct location, an enzyme called **RNA polymerase** helps line up nucleotides to create a **complementary strand** of mRNA.

Since mRNA is a single-stranded molecule, only one of the two strands of DNA is used as a template for the new RNA strand, and the other DNA strand remains dormant.

The enzyme RNA polymerase binds to an area of one of the DNA molecules in the double helix. The enzyme moves along the DNA strand and “reads” the nucleotides one by one. Similar to the process of DNA replication, the new nucleic acid strand elongates in a 5'-3' direction, as shown in Figure 8.5. The enzyme selects complementary bases from available nucleotides and positions them in an mRNA molecule according to the principle of complementary base pairing. The chain of mRNA lengthens until a “stop” message is received. The new strand of RNA is made according to the rules of base pairing:

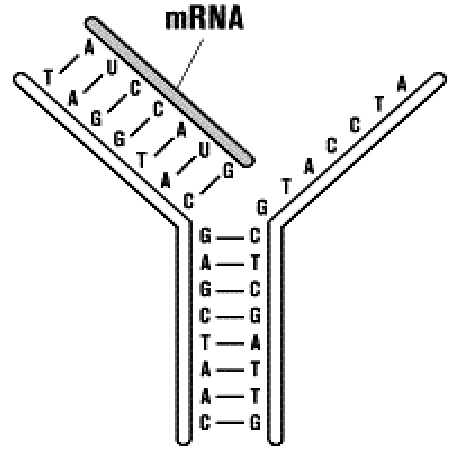


Fig. 9.23Base pairing of mRNA strand to DNA strand

- DNA cytosine pairs with RNA guanine
- DNA guanine pairs with RNA cytosine
- DNA thymine pairs with RNA adenine
- DNA adenine pairs with RNA uracil

For example, the mRNA complement to the DNA sequence TTGCAC is AACGUG. The RNA uses uracil in place of thymine.

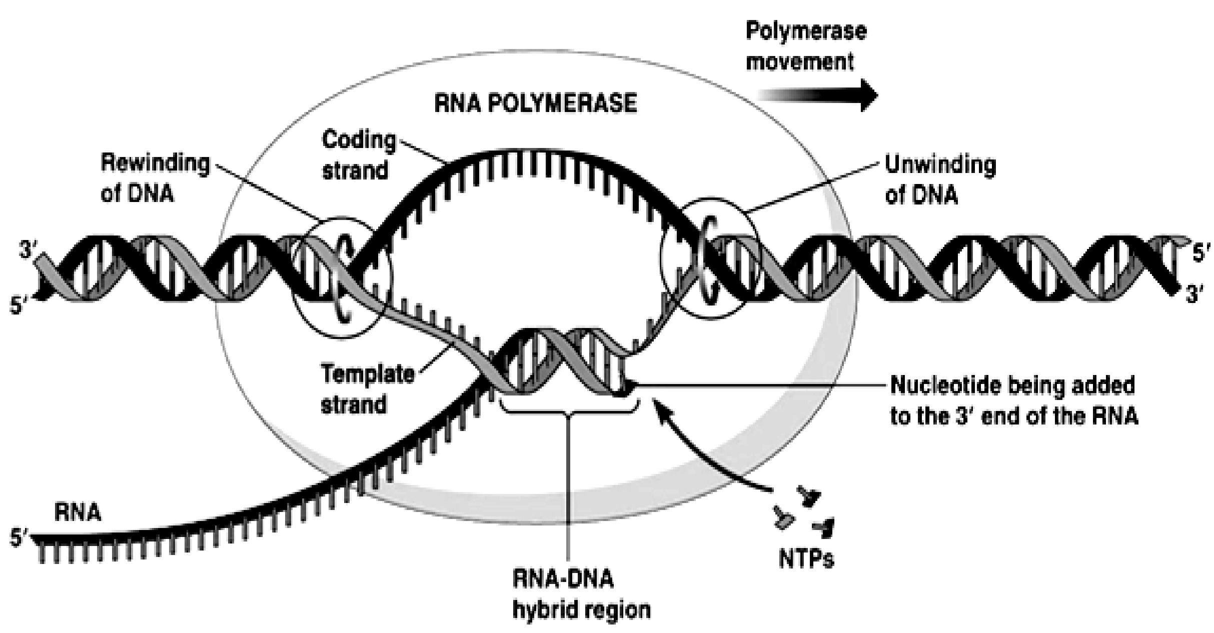


Fig. 9.24 Process of transcription, DNA double helix opens, and the enzyme RNA polymerase synthesizes a molecule of mRNA according to the base sequence of the DNA template

The nucleotides of the DNA strands are read in groups of three. Each group is a *codon*. Thus, a codon may be CGA, or TTA, or GCT, or any other combination of the four bases, depending on the codons complementary sequence in the DNA strand. Each codon will later serve as a "code word" for an amino acid. First, however, the codons are transcribed to the mRNA molecule. Thus, the mRNA molecule consists of nothing more than a series of codons received from the genetic message in the DNA.

After the "stop" codon is reached, the synthesis of the mRNA comes to an end, the new RNA strand is released and the two unzipped DNA strands bind together again to form the double helix. Meanwhile, the mRNA molecule passes through a pore in the nucleus and proceeds into the cellular cytoplasm, where it moves toward the ribosomes located in the cytoplasm or on the rough endoplasmic reticulum. Because the DNA template remains unchanged after transcription, it is possible to transcribe another identical molecule of RNA immediately after the first one is complete. A single gene on a DNA strand can produce enough RNA to make thousands of copies of the same protein in a very short time.

(2) Translation

The genetic code is transferred to an amino acid sequence in a protein through the process of **translation**, which begins with the arrival of the mRNA molecule into the cytoplasm where it binds with ribosomes, the sites of protein synthesis. Ribosomes have three important binding sites: one for mRNA and two for tRNA. The two tRNA sites are labeled as 'A' site and 'P' site. Once the mRNA is in place, tRNA molecules, each associated with specific amino acids, bind to the ribosome in a sequence defined by the mRNA code.

The tRNA molecules then began transporting their amino acids to the ribosomes to meet the mRNA molecule. Transfer RNA (tRNA) molecules can perform this function because of their special structure. It is made up of many nucleotides that bend into the shape of a cloverleaf. At the tail end, tRNA has an acceptor stem that attaches to a specific amino acid. At its head, tRNA has three nucleotides that make up an **anticodon**.

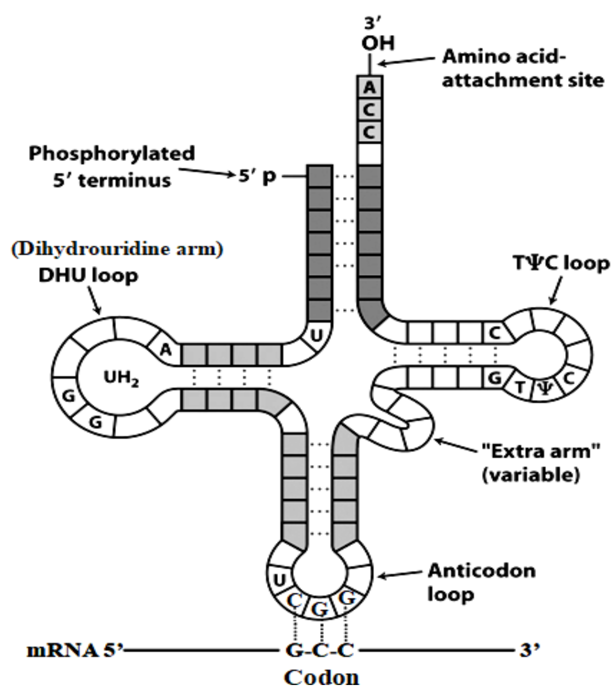


Fig. 9.25 General tRNA structure

An anticodon pairs complementary nitrogenous bases with mRNA. For example, if mRNA has a codon AUC, it will pair with anticodon sequence UAG of tRNA. The tRNA molecules with same anticodon sequence will always carry the same amino acids, ensuring the consistency of the proteins coded for in DNA.

The Process of Translation

Translation begins with the binding of the mRNA chain to the ribosome. The first codon, which is always the start codon methionine, fills the P site and the second codon fills the A site. The tRNA molecule whose anticodon is complementary to the mRNA forms a temporary base pair with the mRNA in the A site. A peptide bond is formed between the amino acid attached to the tRNA in the A site and the methionine in the P site.

The ribosome now slides down the mRNA, so that the tRNA in the A site moves over to the P site, and a new codon fills the A site. (One way to remember this is that the A site brings new amino acids to the growing polypeptide at the P site.) The appropriate tRNA carrying the appropriate amino acid pairs bases with this new codon in the A site. A peptide bond is formed between the two adjacent amino acids held by tRNA molecules, forming the first two links of a chain.

The ribosome slides again. The tRNA that was in the P site is let go into the cytoplasm, where it will eventually bind with another amino acid. Another tRNA comes to bind with the new codon in the A site, and a peptide bond is formed between the new amino acid to the growing peptide chain.

The process continues, one by one, amino acids are added to the growing chain until one of the three stop codons enters the A site. At that point, the protein chain connected to the tRNA in the P site is released. Because of the specificity of tRNA molecules for their individual amino acids, and because of the base pairing between codons and anticodons, the sequence of codons on the mRNA molecule determines the sequence of amino acids in the protein being constructed. And because the codon sequence of the mRNA complements the codon sequence of the DNA, the DNA molecule ultimately directs the amino acid sequencing in proteins. The primary "start" codon on an mRNA molecule is AUG, which codes for the amino acid methionine. Therefore, each mRNA transcript begins with the AUG codon, and the resulting polypeptide begins with methionine.

After the protein has been synthesized completely, it is removed from the ribosome for further processing and to perform its function. For example, the protein may be stored in the Golgi apparatus before being released by the cell or it may be stored in the lysosome as a digestive enzyme. Also, a protein may be used in the cell as a structural component, or it may be released as a hormone, such as insulin. After synthesis, the mRNA molecule breaks up and the nucleotides return to the nucleus. The tRNA molecules return to the cytoplasm to unite with other molecules of amino acids, and the ribosome awaits the arrival of a new mRNA molecule. Thus, translation is complete.

9.12 PLANT TISSUE CULTURE

The term "Plant tissue culture" broadly refers to the *in vitro* cultivation of plant parts under aseptic conditions. Such parts as meristems, apices, axillary buds. Young inflorescence, leaves, stems, and roots have been cultured. A controlled aseptic environment and suitable nutrient medium are the two chief requirements for successful tissue culture. These essential nutrients include inorganic salts, a carbon and energy source, vitamins and growth regulators. The basic technology can be divided into five classes, depending on the material being used: Callus, organ, meristem, and protoplast and cell culture. The technique of embryo, ovule, ovary, anther and microspore culture are used and can yield genotypes that cannot easily be produced by conventional methodology.

Plant tissue culture is a collection of techniques used to sustain or grow plant cells, tissues or organs under sterile conditions on a nutrient culture medium of known composition. Plant tissue culture is used to produce clones of plant in a method called micropropagation. Plant tissue culture relies on the fact that many plant cells have the ability to regenerate into a whole plant in a process called **Totipotency**. Single cells without cell walls (protoplasts), pieces of leaves, stems or roots can often be used to generate a new plant on culture media given the required nutrients and hormones. The plant part obtained from a plant to be cultured is called explant while the main plant it is obtained from is called mother plant. **Explant** can be taken from different plant parts such as shoots, leaves, stems, flowers, roots, single undifferentiated cells etc.

A small tissue excised from any part of the plant is called explant which is the starting point. It can be initiated from any part of plant- root, stem, petiole, leaf or flower, choice of explant varies with species. Meristems are more responsive and give better success as they are actively dividing. The physiological state of the plant also has an influence on its response to initiate tissue culture. Therefore, the parent plant must be healthy and free from obvious signs of disease or decay. Aseptic environment during culture is required to avoid contamination from microorganisms. Since plant cell division is slower compared to the growth of bacteria, fungi and even minor contaminants can easily overgrow the plant tissue culture. Therefore, all the materials like glassware, instruments, medium, explant etc. to be used in culture work must be freed of microbes. Laminar flow is a mandatory prerequisite for any tissue culture laboratory for contamination free work.

Totipotency

Capacity of higher organism cell to differentiate into entire organism, totipotent cell contains all genetic information necessary for complete development. When an explant from differentiated tissue is used for culture on a nutrient medium, the non-dividing quiescent cells first undergo certain changes to achieve a meristematic state. The phenomenon of the reversion of mature cells to the meristematic state leading to the formation of callus is called “dedifferentiation”. The component cells of the callus have the ability to form a whole plant a phenomenon described as “dedifferentiation”. These two phenomenon's of dedifferentiation and “redifferentaition” are inherent in the capacity described as “cellular Totipotency”, a property found only in plant cell and not in animal cells. In other words, while a differentiated plant cell retain its capacity to give rise to whole plant, an animal cell loses its capacity of regeneration after differentiation. Although, generally a callus phase is involved before the cell can undergo redifferentaition leading to regeneration of whole plant, but rarely, the dedifferentiated cells give rise to whole plant directly without an intermediate callus phase.

Tools and Technique Used For Plant Tissue Culture

1. **pH and pH Meter:** An approximate idea of the pH of a solution can be obtained using indicators. These are organic compounds of natural or synthetic origin whose Colour is dependent upon the pH of the solution. Indicators are usually weak acids, which dissociate in solution. A standard pH meter has two electrodes, one glass electrode for measuring pH and the other calomel reference electrode
2. **Autoclave:** Autoclave is used to sterilize medium, glassware and tools for the purpose of plant tissue culture. Sterilization of material is carried out by increasing moist heat (121°C) due to increased pressure inside the vessel (15-22 psi or 1.02 to 1.5 kg/cm2) for 15 minutes for routine sterilization. Moist heat kills the microorganism and makes the material free from microbes.
3. **Plant Growth Chamber:** Plant growth chambers can be constructed in a suitable sized room or can be purchased as commercially available equipment. Thermal insulation of walls increases the efficiency of the cooling system. Essentially plant growth chamber has three environmental control systems:
   (i) Light-intensity and duration cycle control.
   (ii) Temperature control and regulation.
   (iii) Humidity control and regulation.
4. **Colorimeter:** The most commonly used method for determining the concentration of biochemical compounds is colorimetry. It uses the property of light such that when white light passes through a coloured solution, some wavelengths are absorbed more than others.
5. **Laminar Air Flow Bench:** Laminar air flow (LAF) bench is the main working table for aseptic manipulations related to plant tissue culture. This is equipment fitted with High Efficiency Particulate Air (HEPA) Filters, which allow air to pass but retain all the particles and micro-organisms.

Fig.9.26 Laminar flow
(Tissue culture work in sterilized conditions)

6. **Methods of Sterilization:** Plant tissue culture requires contamination free environment, tools and cultures or strict maintenance of germ free system in all the operations, known as **asepsis**.

7. Microscopy:

(a) Electron Microscopy: Electron microscopy permits a detailed study of sub-cellular organelles as its resolving power is much greater than that of the light microscope.

(b) SEM: Scanning electron microscope (SEM) provides surface views of whole structure of specimen. Normally, specimens are coated with a thin film of metal under vacuum.

(c) Light Microscopy: Bright field microscopy is absolutely indispensable tool for cell biologists. This is required for routine observations of cells, cellular differentiation and pigmentation.

8. **Centrifugation:** A centrifuge is an instrument which produces centrifugal force by rotating the samples around a central axis with the help of an electric motor.
9. **Chromatography:** (meaning 'colored writing') is a technique to separate molecules on the basis of differences in size, shape, mass, charge and adsorption properties.
10. **Thermometer:** It is a device that measures temperature or temperature gradient using a variety of different principles.
11. **Hygrometer:** The instruments used for measuring humidity. A simple form of a hygrometer is specifically known as a "Psychrometer" and consists of two thermometers, one of which includes a dry bulb and the other of which includes a bulb that is kept wet to measure wet-bulb temperature.
12. **LUX Meter:** Lux is a measurement of the overall intensity of light within an environment for any given area or distance from the source or lux is the amount of light in an environments perceived by the human eye.
13. **Medium and Its Preparation:** The media used by earlier workers were based on Knop's solution. Subsequently media developed by White (1943) and Heller (1953) were used. Murashige and Skoog's medium (Murashige and Skoog, 1962) is a land mark in plant tissue culture research and is the most frequently used medium for all types of tissue culture work.

Plant Growth Regulators

Plant growth regulators (also called plant hormones) are numerous chemical substances that profoundly influence the growth and differentiation of plant cells, tissues and organs. Plant growth regulators function as chemical messengers for intercellular communication. There are currently five recognized groups of plant hormones: auxins, gibberellins, cytokinins, abscisic acid (ABA) and ethylene. They work together coordinating the growth and development of cells. Ethylene is mainly involved in abscission and flower senescence in plants and is rarely used in plant tissue culture. In addition to the five principal growth regulators, two other groups sometimes appear to be active in regulating plant growth, the brassino steroids and polyamines.

Hormones used in Plant Tissue Culture:

1. Auxins
2. Cytokinins
3. Gibberellins
4. Abscisic Acid (ABA)

5. Polyamines

Culture Media

Culture medium is the most important part of plant tissue culture. A successful plant tissue culture system largely relies on a right culture medium formula. Plant tissue culture media usually contains inorganic elements, organic compounds and a support matrix. Culture media provides the cultures the necessary inorganic nutrients that are usually available from soil. In addition, they also provide the cultures the necessary organic compounds such as vitamins, and carbon source, which are usually produced in plants. Sometimes, plant growth regulators are added to the medium to stimulate cell division and/or differentiation.

Another important function of a culture medium is creating a necessary environment for plants to grow. For example, solid media, functioning like the soil, provides a physical support for the cultures to keep contact with air for respiration, and for regenerated plantlets to root into. A liquid medium enables explants to keep constant, maximum contact with nutrient supplies. A selective reagent may also be included in a culture medium to restrict the growth of certain cultures. Therefore, medium formulas vary depending upon the purpose of plant tissue culture. Different media may also be used during a plant tissue culture process.

Culture Technique in Plant Tissue Culture

Preparation of plant tissues for tissue culture is performed under aseptic conditions under HEPA (High efficiency particulate air) filtered air provided by laminar flow cabinet. The tissue is grown in sterile containers inside Petridish, test tube or flasks in a growth room with controlled temperature and light intensity. Living plant materials are usually contaminated on their surfaces (or sometimes interior) with microorganisms, so their surfaces are stressed in chemical solutions (e.g. alcohol and sodium hypochlorite). The sterile explants are placed on the solid and liquid media are generally composed of inorganic salts, organic nutrients, vitamins and plant hormones. Solid media are prepared from liquid media with the addition of gelling agent (agar). The composition of the medium, particularly the plant hormones and the nitrogen source has profound effects on the morphology of the tissues that grow from the initial explant. For instance, an excess of auxin will result in a proliferation of roots while an excess of cytokinin may yield to shoots proliferation. A balance of both auxin and cytokinin will often produce an unorganized growth of cells called callus, but the morphology of the outgrowth will depend on the plant species as well as the medium composition.

Classification of Plant Tissue Culture Technique

1. Embryo Culture: For embryo culture, embryos are excised from immature seeds, usually under a ‘hood’, which provides a clean aseptic and sterile area. Sometimes, the immature seeds are surface sterilized and soaked in water for few hours, before the embryos are excised. The excised embryos are directly transferred to a culture dish or culture tube containing synthetic nutrient medium. Entire operation is carried out in the 'laminar flow cabinet' and the culture plates or culture tubes with excised embryos are transferred to a culture room maintained at a suitable temperature, photoperiod and humidity. The frequency of excised embryos that gives rise to seedlings generally varies greatly and medium may even have to be modified made for making Interspecific and Intergeneric crosses within the tribe Triticeae of the grass family. The hybrids raised through culture have been utilized for

a) Phylogenetic studies and genome analysis.

b) Transfer of useful agronomic traits from wild genera to the cultivated crops and

c) To raise synthetic crops like triticale by producing amphiploids from the hybrids.

Embryo culture has also been used for haploid production through distant hybridization followed by elimination of chromosomes of one of the parent in the hybrid embryos cultured as above.

Application of Embryo Culture

i) Recovery of distant hybrids.

ii) Recovery of haploid plants from interspecific crosses.

iii) Propagation of orchids.

iv) Shortening the breeding cycle

v) Overcoming dormancy.

In addition ovule and ovary can also be cultured.

2. Meristem Culture: In attempts to recovery pathogen free plants through tissue culture techniques, horticulturists and pathologists have designated the explants used for initiating cultures as 'shoot –tip', tip, meristem and meristem tip. The portion of the shoot lying distal to the youngest leaf primordium is called the **apical meristem**. The apical meristem together with one to three young leaf primordia constitute the shoot apex. In most published works explants of larger size have been cultured to raise virus-free plant. The explants of such a size should be infect referred to as shoot-tips.

However, for purpose of virus or disease elimination the chances are better if cultures are initiated with shoot tip of smaller size comprising mostly meristematic cells. Therefore, the term 'meristem' or meristem-tip' culture is preferred for *in vitro* culture of small shoot tips. The *in vitro* techniques used for culturing meristem tips are essentially the same as those used for aseptic culture of plant tissues. Meristem tips can be isolated from apices of the stems, tuber sprouts , leaf axils , sprouted buds or cuttings or germinated seeds.

Application of Meristem Culture

i) Vegetative propagation

ii) Recovery of virus free stock.

iii) Germplasm exchange

iv) Germplasm conservation

3. Anther or Pollen Culture: Angiosperms are diploid and the only haploid stage in their life cycle being represented by pollen grains. From immature pollen grains we can sometimes raise cultures that are haploid. These haploid plants have single completes set of chromosomes. Their phenotype remains unmasked by gene dominance effects. When pollen grains of angiosperm are cultured, they undergo repeated divisions.

In *Datura innoxia* the pollen grains from cultured anther can form callus when grown on a media supplemented with yeast extract or casein hydrolysate. Similarly, when isolated anthers are grown on media containing coconut milk or kinetin, they form torpedo- shaped embryoids which in due course grow into small haploid plantlets. The usual approach in anther culture is that anthers of appropriate development stage are excised and cultured so that embryogenesis occurs. Alternatively pollen grains may be removed from the anther, and the isolated pollen is then cultured in liquid medium. Cultured anthers may take up to two months to develop into plantlets.

Application of Anther or Pollen Culture

Pollen culture or anther culture is useful for production of haploid plants. Similarly, haploid plants are useful in plant breeding in variety of ways as follows:

i) Releasing new varieties through F1 double haploid system.

ii) Selection of mutants resistant to diseases.

iii) Developing asexual lines of trees or perennial species.

iv) Transfer of desired alien gene.

v) Establishment of haploid and diploid cell lines of pollen plant.

4. Tissue and Cell Culture: Single cells can be isolated either from cultured tissues or from intact plant organs, the former being more convenient than the latter. When isolated from culture tissues, the latter is obtained by culturing an organized tissue into callus. The callus may be separated from explant and transferred to fresh medium to get more tissue. Pieces of undifferentiated calli are transferred to liquid medium, which is continuously agitated to obtain a suspension culture. Agitation of pieces break them into smaller clumps and single cells, and also maintains uniform distribution of cells clumps in the medium. It also allows gases exchange. **Suspension cultures** with single cells can also be obtained from impact plant organs either mechanically or enzymatically. Suspension cultures can be maintained in either of the following two forms:

A. Batch culture: are initiated as single cells in 100-250 ml flasks and are propagated by transferring regularly small aliquots of suspension to a fresh medium.

B. Continuous culture: are maintained in steady state for long periods by draining out the used medium and adding fresh medium, in this process either the cells separated from the drained medium are added back to suspension culture or addition of medium is accompanied by the harvest of an equal volume of suspension culture.

Application of Cell Culture

i) Mutant selection
ii) Production of secondary metabolites or biochemical production.
iii) Biotransformation
iv) Clonal propagation
v) Somaclonal variations

Practical Applications of Plant Tissue Culture

The use of plant cells to generate useful products and/or services constitutes plant biotechnology. In plant biotechnology, the useful product is a plantlet. The plantlets are used for the following purposes.

1. Rapid Clonal Propagation: A clone is a group of individuals or cells derived from a single parent individual or cell through asexual reproduction. All the cells in callus or suspension culture are derived from a single explant by mitotic division. Therefore, all plantlets regenerated from a callus/suspension culture generally have the same genotype and constitute a clone. These plantlets are used for rapid Clonal propagation. This is done in oil palm.

2. Somaclonal Variation: Genetic variation present among plant cells of a culture is called Somaclonal variation. The term Somaclonal variation is also used for the genetic variation present in plants regenerated from a single culture. This variation has been used to develop several useful varieties.

3. Transgenic Plants: A gene that is transferred into an organism by genetic engineering is known as transgene. An organism that contains and expresses a transgene is called transgenic organism. The transgenes can be introduced into individual plant cells. The plantlets can be regenerated from these cells. These plantlets give rise to the highly valuable transgenic plants.

4. Induction and Selection of Mutations: Mutagens are added to single cell liquid cultures for induction of mutations. The cells are washed and transferred to solid culture for raising mutant plants. Useful mutants are selected for further breeding. Tolerance to stress like pollutants, toxins, salts, drought, flooding, etc. can also be obtained by providing them in culture medium in increasing dosage. The surviving healthy cells are taken to solid medium for raising resistant plants.

5. Resistance to Weedicides: It is similar to induction of mutations. Weedicides are added to culture initially in very small concentrations. Dosage is increased in subsequent cultures till the desired level of resistance is obtained. The resistant cells are then regenerated to form plantlets and plants.

9.13 SUMMARY

1. **Amitosis** is a process of division found in prokaryotic cell. It occurs in lower group of organisms like protozoa, endosperm tissue of flowering plants and in cell of foetal membrane of vertebrates.

2. Every growing cell undergoes a cell cycle that consists of two phase an **interphase** and **mitotic** phase.
3. **Karyokinesis** is nuclear change taking place during mitosis and is divided into four phases namely prophase, metaphase, anaphase and telophase.
4. **Prophase** is the first phase and is the longest phase. In prophase chromatin becomes condensed resulting in formation of chromosomes. Nuclear membrane along with nucleolus disappears during late prophase. Single centriole divides into two and for each centriole astral rays are formed. Centrioles are absent in plant cells.
5. During metaphase chromosomes get arranged at equator. Centromere of chromosomes is attached to spindle fibres. **Metaphase** stage is the best stage to observe and count chromosomes.
6. Separation of chromosomes occurs in anaphase stage. During anaphase movement of chromatids occurs towards opposite poles. **Anaphase** is the shortest phase of mitosis.
7. Events of prophase are reversed in **telophase**. In telophase nuclear membrane and nucleolus reappear along with formation of chromatin network from chromosomes.
8. As a result after telophase, cell contains two separate nuclei (one at each pole). After four phases of karyokinesis, cytokinesis occurs. **Cytokinesis** is simply division of cytoplasm.
9. There is different in how the process of cytokinesis occurs in plant cell and in animal cells. A **cell furrow** is formed in animal cells which divides the cell into two cells. In plant cells, cytokinesis occurs by formation of **cell plate**.
10. Mitosis is essential for growth and development of organism and also for repair of damaged tissues. Mitosis is the basis of vegetative reproduction. **Colchicines** are an alkaloid used to arrest mitosis at metaphase stage.
11. Mitosis is known as **equational division** as daughter cells formed have same number of chromosomes as the mother cell.
12. In gonads, occurs reductional division called **meiosis**. After meiosis four daughter cells are formed with half the number of chromosomes present in mother cell. Cells which undergo meiosis are called **meiocytes**. Meiosis consists of two successive divisions called as **meiosis-I** and **meiosis-II**. Meiosis I is also known as **heterotypic** division and meiosis II is known as **homotypic** division.
13. Meiosis-I is divided into four phases prophase I, metaphase I, anaphase I and telophase I, whereas, meiosis II is divided into prophase II, metaphase II, anaphase II and telophase II.
14. **Prophase-I** is the longest phase and is further divided into sub-stages; Leptotene, Zygotene, Pachytene, diplotene and Diakinesis.
15. In **Leptotene** chromosomes are seen in the form of long thin threads.
16. In **Zygotene** stage, pairing between homologous chromosomes occurs. This is also called as **synapsis** formation. As a result of synapsis formation, bivalents are formed. During Zygotene formation of **synaptonemal complex** also occurs which facilitates genetic recombination.

17. In **Pachytene** stage of prophase-I shortening and thickening of bivalents occur. Each of the bivalent is made of four chromatids known as tetrad. **Crossing-over** between non-sisters chromatids occur in Pachytene.
18. In **Diplotene** separation of paired chromosomes occur but chromosomes remains attached at chiasmata.
19. In **Diakinesis** contraction of chromosomes increases. Number of chiasmata gets reduced in Diakinesis, known as **terminalization**.
20. In **Metaphase-I** stage, bivalents get arranged on equatorial plate.
21. Separation of homologous chromosomes occurs at **Anaphase I**. Separation of tetrad into dyads is known as **disjunction**, which results in reduction of chromosome number to half.
22. In **Telophase** chromosomes gets grouped at poles and nuclear membrane reappear.
23. **Meiosis II** is equational division, which is similar to mitosis.
24. In **Prophase II** nuclear membrane disappear, chromosomes become visible along with formation of spindle fibres.
25. Chromosomes get arranged on equator at **metaphase II**.
26. Division of centromere and separation of chromatids occur during **anaphase II**.
27. Reformation of nucleoli and formation of nuclear membrane occurs during **telophase II**.

28- Robert Hooke (1665) was first to discover and use the term cell.

9.14 GLOSSARY

Autotroph: Any organism capable of self-nourishment by using inorganic materials as a source of nutrients and using photosynthesis or chemosynthesis as a source of energy, as most plants and certain bacteria and protists.

Cell Biology: Sub-discipline of biology that focuses on the study of the basic unit of life, the cell.

Cell wall: Of many cells (not animal cells), a semi-rigid but permeable structure that surrounds the plasma membrane; helps a cell retain its shape and resist rupturing.

Cell: Smallest unit that still displays the properties of life; it has the capacity to survive and reproduce on its own.

Central vacuole: In many mature, living plant cells, an organelle that stores amino acids, sugars, and some wastes; when it enlarges during growth, it forces the cell to enlarge and increase its surface area.

Chromosome: A long, stringy aggregate of genes that carries heredity information (DNA) and is formed from condensed chromatin.

Cisternae: A cisterna (plural cisternae) is a flattened membrane disk of the endoplasmic reticulum and Golgi apparatus.

Colicin: Any bacteriocin produced by certain strains of Escherichia coli and having a lethal effect on strains other than the producing strain.

Cytoplasm: Consists of all of the contents outside of the nucleus and enclosed within the cell membrane of a cell.

Cytosol: Semi-fluid component of a cell's cytoplasm.

Endoplasmic reticulum: The endoplasmic reticulum is a type of organelle in eukaryotic cells that forms an interconnected network of flattened, membrane-enclosed sacs or tube-like structures known as cisternae.

Eukaryote: Any organism whose cells have a cell nucleus and other organelles enclosed within membranes. Eukaryotes belong to the domain Eukaryota, and can be single-celled or multicellular.

Flagella: A long, lash-like appendage serving as an organ of locomotion in protozoa, sperm cells, etc.

Golgi Bodies: A complex of vesicles and folded membranes within the cytoplasm of most eukaryotic cells, involved in secretion and intracellular transport.

Histone: Any of a group of five small basic proteins, occurring in the nucleus of eukaryotic cells, that organize DNA strands into nucleosomes by forming molecular complexes around which the DNA winds.

Homeostasis: It refers to the ability of the body to maintain a stable internal environment despite changes in external conditions.

Lysosome: An organelle in the cytoplasm of eukaryotic cells containing degradative enzymes enclosed in a membrane.

Mycoplasma: It is a genus of bacteria that lack a cell wall around their cell membrane. Without a cell wall, they are unaffected by many common antibiotics such as penicillin or other β-lactam antibiotics that target cell wall synthesis.

Parenchyma: The fundamental tissue of plants, composed of thin-walled cells able to divide.

Prokaryote: A prokaryote is a unicellular organism that lacks a membrane-bound nucleus, mitochondria, or any other membrane-bound organelle.

Proteins: Proteins are large biomolecules, or macromolecules, consisting of one or more long chains of amino acid residues. It performs a vast array of functions within organisms, including catalyzing metabolic reactions, DNA replication, responding to stimuli, and transporting molecules from one location to another.

Ribosome: A tiny, somewhat mitten-shaped organelle occurring in great numbers in the cell cytoplasm either freely, in small clusters, or attached to the outer surfaces of endoplasmic reticulum, and functioning as the site of protein manufacture.

Thylakoid: A flattened sac or vesicle lined with a pigmented membrane that is the site of photosynthesis, in plants and algae occurring in interconnected stacks constituting a granum of the chloroplast, and in other photosynthesizing organisms occurring either singly or as part of the cell membrane or other structure.

Tonoplast: A membrane separating a vacuole from the surrounding cytoplasm in a plant cell.

Vesicle: It is a small structure within a cell, or extracellular, consisting of fluid enclosed by a lipid bilayer. Vesicles form naturally during the processes of secretion (exocytosis), uptake (endocytosis) and transport of materials within the cytoplasm.

9.15 SELF ASSESSMENT QUESTIONS

9.15.1 Objective type Questions:

1. Cells originate from-
   (a) Bacterial fermentation (b) Pre existing cells
   (c) Abiotic materials (d) Regeneration of old cells

2. The smallest size of cell that can be seen with an unaided eye is-
   (a) 1 micron (b) 10 micron
   (c) 100 micron (d) 1000 micron

3. The term cell was first used by-
   (a) Robert Hooke (b) Harvey
   (c) Hopkins (d) Fleming

4. What Robert Hooke had discovered in the thin section of cork as a cell was really a-
   (a) Cellulose (b) Nuclei
   (c) Protoplasm (d) Cell walls

6. The prokaryotic cells are characterized by
   (a) A distinct nuclear membrane (b) Distinct chromosomes
   (c) Absence of chromatin material (d) Absence of nuclear membrane

7. Animal and plant cell differ in their
   (a) Movement (b) Growth
   (c) Nutrition (d) Respiration

8. Protoplasm is a
   (a) Liquid (b) Solid
   (c) Colloidal solution (d) Crystalloid colloidal

9. Which of the following is a common feature of all cells?
   (a) Intracellular organelles (b) A lipid cell membrane
   (c) A nuclear membrane (d) An RNA genome

10. What is the main difference between prokaryotes and eukaryotes?
   (a) Prokaryotes can't undergo cell division (b) Prokaryotes have no internal membranes
   (c) Prokaryotes have no DNA (d) Prokaryotes have no cytosol

11. Prokaryotic cells have a specialized material with them called as?
    (a) Peptidoglycan (b) Pectin
    (c) Peptidoaminase (d) Peptidoglucose

12. Organism which lack mitosis division and use binary fission method for cell division are known as?
    (a) Eukaryotes (b) Prokaryotes
    (c) Yeast (d) Fungi

13. Select one which is not true for Ribosome
    (a) Made up of two subunits (b) Form polysomes
    (c) May attached to mRNA (d) Have role in protein synthesis

14. What is a Tonoplast?
    (a) Outer membrane of mitochondria
    (b) Inner membrane of chloroplast
    (c) Membrane boundary of the vacuole of plant cells
    (d) Cell membrane of a plant cell

15. Which of the following is not true of a eukaryotic cell?
    (a) It has 80S type of ribosome present in the mitochondria
    (b) It has 80S type of ribosome present in the cytoplasm
    (c) Mitochondria contain circular DNA
    (d) Membrane bound organelles are present

16. Plastid differs from mitochondria on the basis of one of the following features. Mark the right answer.
    (a) Presence of two layers of membrane
    (b) Presence of ribosome
    (c) Presence of chlorophyll
    (d) Presence of DNA

17. Which of the following statements is not true for plasma membrane?
    (a) It is present in both plant and animal cell
    (b) Lipid is present as a bilayer in it
    (c) Proteins are present integrated as well as loosely associated with the lipid bilayer
    (d) Carbohydrate is never found in it

1.9.1 Answer key: 1- (b), 2- (c), 3-(a), 4-(d), 5-(c), 6- (d), 7-(c), 8-(c), 9-(b), 10- (b), 11-(a), 12-(b), 13-(d), 14-(c), 15-(a), 16-(c), 17-(c).

9.16 REFERENCES

- Cell Biology Basics (PDF35P)
- David L. Schultz
- Basics of Cell Biology Literature Reading(PDF49P)
- Ge Yang, Department of Biomedical Engineering, Carnegie Mellon University
- "Campbell, Neil A.; Brad Williamson; Robin J. Heyden (2006). Biology: Exploring Life. Boston, Massachusetts: Pearson Prentice Hall. ISBN 0-13-250882-6.
- Alan Chong Tero (1990). Achiever's Biology. Allied Publishers. p. 36.
- Maton, Anthea (1997). Cells Building Blocks of Life. New Jersey: Prentice Hall.
- Campbell Biology—Concepts and Connections. Pearson Education. 2009. p. 320.
- Michie K, Löwe J (2006). "Dynamic filaments of the bacterial cytoskeleton". Annu Rev Biochem. 75: 467–92. doi:10.1146/annurev.biochem.75.103004.142452. PMID 16756499.
- Prokaryotes. Newnes. Apr 11, 1996. ISBN 9780080984735.
- Becker, Wayne M.; et al. (2009). The world of the cell. Pearson Benjamin Cummings. p. 480.
- www.ncbi.nlm.nih.gov
- www.biologyjunction.com/cell
- www.biologycorner.com/anatomy/cell
- www.biologydiscussion.com
- www.dictionary.com
- www.biologyguide.net
- www.biology.tutorvista.com

9.17 SUGGESTED READINGS

- Current Frontiers and Perspectives in Cell Biology. Stevo Najman
- Cell Biology and Genetics. Twesigye, Charles K.
- Cell Biology, Genetics, Molecular biology, Evolution and Ecology. P.S. Verma, V.K. Agarwal.
- B. Alberts et al (2008) 5th Edition, *Molecular Biology of the Cell*, Garland
- J.M. Berg (2006) 6th Edition, *Biochemistry*, Freeman
- A.J.F. Griffith et al (2004) 8th Edition *An introduction to Genetic Analysis*, Freeman
- Nelson, D. L. & Cox, M. M., *Lehninger Principles of Biochemistry.* Freeman, 6th edition, 2013
- Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter P. *Molecular Biology of the Cell.* Garland Science, 6th edition 2014
- Lodish, H., Berk, A., Zipursky, S. L., Matsudaira, P., Baltimore, D. and James Darnell, J. *Molecular Cell Biology* , Freeman, 7th edition 2013

9.18 TERMINAL QUESTIONS

1. Write a note on prokaryotic and eukaryotic cell.
2. Differentiate between animal and plant cell.
3. Give a detailed account of cell dividion.
4. Write a detailed note on structure and composition of DNA.
5. Write a detailed note on structure and composition of RNA.
6. Give a detailed account of protein synthesis.
7. Write a note on tools and techniques of plant tissue culture.

UNIT-10 BIODIVERSITY CONSERVATION

Contents:

10.1 OBJECTIVES

After reading this unit students will be able-

- to know about the concepts of the biodiversity conservation
- acquaint with the biodiversity profile at national as well as global
- learn about the various threats to the biodiversity

10.2 INTRODUCTION

The term ‘‘biodiversity’’ was first used in its long version (biological diversity) by (Lovejoy, 1980) and is most commonly used to describe the number of species.

From hot arid deserts of the Sahara, through the lush green rainforests of the Amazon, to the ocean depths and bright corals, our natural world is a marvel of different landscapes, materials, colours and textures. The land, air and seas of our planet are home to the tiniest insects and the largest animals, which make up a rich tapestry of interconnecting and interdependent forces.

Biodiversity found on Earth today consists of many millions of distinct biological species, the product of four billion years of evolution.

E. O. Wilson first used the term biodiversity in the literature in, the concept of biological diversity from which it arose had been developing since the nineteenth century and continues to be widely used.

Biodiversity encompasses the variety of life, at all levels of organization, classified both by evolutionary (phylogenetic) and ecological (functional) criteria.

The most acceptable definition of the biodiversity is the one held by the CBD which was signed by the more than 180 nations on June 5, 1992 at Rio-De-Janerio. But, there are at least 12 formal definitions. The CBD states that Biological Diversity means the variability among living organisms from all sources, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complex of which they are part, this includes diversity within species, between species and of ecosystems.

In other words Biodiversity is the variety of life in all many manifestations. It encompasses all forms, levels and combinations of natural variations.

The actual definitions as per the conventions: the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and technologies and by appropriate funding.

But another definition as per the WCMC (1992) in their edited book {Global Biodiversity} is "Diversity is a concept which refers to the range of variation or differences among some sets of entities: biological diversity thus refers to variety within the living world. Thus the term is often used to describe the number and variability of living organisms".

Ecosystem Diversity --------------BIODIVERSITY------------- Genetic Diversity

|

Species Diversity

However, the word "Biodiversity" is relatively new, and is thought to have first been coined as a contraction of the term "biological diversity" in 1985 and then popularised by a number of authors (Nematology: Advances and Perspectives, Vol. 1 By Z. X. Chen, S. Y. Chen, Donald Ward Dickson p 439)

Biodiversity is the variety of life on Earth, it includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems.

It also refers to the interrelatedness of genes, species, and ecosystems and in turn, their interactions with the environment. Three levels of biodiversity are commonly discussed — **genetic, species and ecosystem diversity.**

1. **Genetic diversity** is all the different genes contained in all the living species, including individual plants, animals, fungi, and microorganisms.
2. **Species diversity** is all the different species, as well as the differences within and between different species.
3. **Ecosystem diversity** is all the different habitats, biological communities and ecological processes, as well as variation within individual ecosystems.

10.3 BASIC CONCEPT

"Without knowing it, we utilize hundreds of products each day that owe their origin to wild animals and plants. Indeed our welfare is intimately tied up with the welfare of wildlife. Well many conservationists proclaim that by saving the lives of wild species, we may be saving our own."

Norman Myers

Biodiversity is a shorthand way of saying biological diversity. Biodiversity includes all of the various forms of life on Earth. You might also know it as "the web of life". This web of life is divided into three parts to help simplify a very complex concept:

- Genes

- Species
- Ecosystems

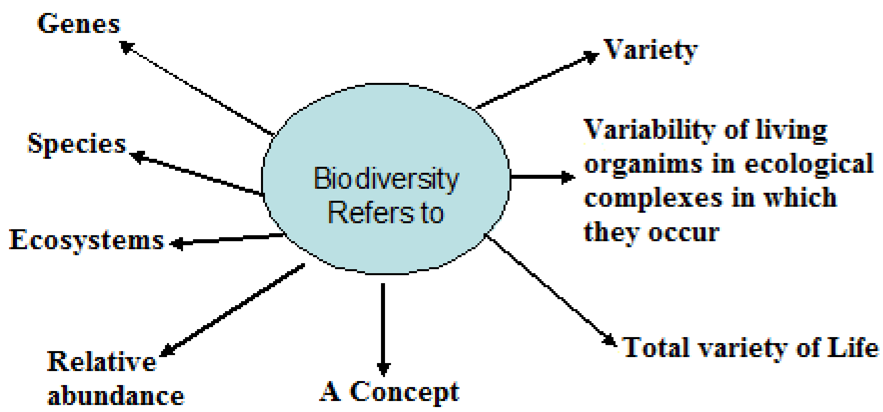


Fig.10.1 Biodiversity: Further Concepts
(Source: Modified from Biodiversity by D.L. Perlman and G. Andelson, 1997)

Michael J. Jeffries (1997) has elaborated biodiversity concept in Biodiversity and Conservation which directly and indirectly touches all areas of human lives. The concept of biodiversity also covers the following:

Evolution: Ecological processes have evolutionary consequence. They interact with genetic diversity via adaptation, micro-evolution and specialization.

Diversification of Genes: Selection and maintenance of genetic diversity.

Specialization of Diversity: There are three components to biodiversity: genetic, organizational and ecological. It covers conservation of genetic diversity, species variation and ecosystem diversity.

10.4 BIODIVERSITY AT GLOBAL LEVEL

Conservative estimates of the existing biodiversity is ten million species, but if estimates for insects are correct then it could be around 30 million species, we have till now enlisted about 1.4 million species. It includes among others about 98% birds, 95% reptiles and amphibians, 90% fish and about 85% higher plants known to exist on this Earth (source: http://www.yourarticlelibrary.com/uncategorized/biodiversity-at-global-national-and-local-levels-explained-with-diagram/28262/). Floral and faunal diversity at global level are presented in Tables 2 and 2.

Table 1. Biodiversity Profile: World: Plant Kingdom

Group	**No. of species**
Bacteria	4,000
Viruses	4,000
Algae	40,000
Fungi	72,000
Lichens	17,000
Bryophyta	16,000
Pteridophyta	13,000
Gymnosperms	750
Angiosperms	2,50,000

Table 2. Biodiversity Profile: World: Animal Kingdom

Group	**No. of species**
Protista	31,259
Mollusca	66,535
Arthropoda	9,87,949
Other Invertebrates	87,121
Protochordata	2,106
Pisces	21,723

Amphibia	5,150
Reptilia	5,817
Aves	9,026
Mamalia	4,629

10.5 BIODIVERSITY AT NATIONAL LEVEL

India, with 2.4% of the world's area, has over 8% of the world's total biodiversity, making it one of the 12 mega-diverse countries in the world. This status is based on the species richness and levels of endemism recorded in a wide range of taxa of both plants and animals. This diversity can be attributed to the vast variety of landforms and climates, resulting in habitats ranging from tropical to temperate and from alpine to desert. Adding to this is a very high diversity of human-influenced ecosystems, including agricultural and pasture lands, and a diversity of domesticated plants and animals, one of the world's largest. India is also considered one of the world's eight centres of origin of cultivated plants. Being a predominantly agricultural country, India also has a mix of wild and cultivated habitats, giving rise to very specialized biodiversity, which is specific to the confluence of two or more habitats.

Natural Ecosystems

Biogeographic Zones of India

Rodgers *et al*., (2002) recognizes ten biogeographic zones divided into twenty-six biotic provinces in India. Biogeographic zones of India and their spatial extent is presented in Table 3.

Table -3 Biogeographic zones of India and their spatial extent

S.No.	Zone	Area	% of India’s land area
1	Trans-Himalaya	184823	5.62
2	Himalaya	210662	6.41
3	Desert	215757	6.56
4	Semi-Arid	545850	16.60
5	Western Ghats	132606	4.03

6	Deccan Peninsula	1380380	41.99
7	Gangetic Plain	354782	10.79
8	Coasts	82813	2.52
9	Northeast	171341	5.21
10	Islands	8249	0.25
	Grand Total	**3287263**	**100.00**

Natural Terrestrial Ecosystems

India, due to its varied physical features and its geographical location, experiences almost all kinds of climate, from tropical to alpine and from desert to humid. On the basis of temperature, the landmass of India can be broadly classified into four zones: a. *Tropical zone*, which is very hot round the year and does not have a winter, b. *Sub-tropical zone,* which is hot for most of the year but with a cool winter, c. *Temperate zone*, which has a warm summer and a pronounced winter, and, *Arctic or Alpine zone*, which has a short summer and a long and severe winter d. *Natural terrestrial ecosystems* are of the following broad kinds: forests, grasslands, deserts and permanently snow-bound areas (Source: Natural Terrestrial Ecosystems Thematic BSAP 2002).

Forests

According to FSI (2002), forest cover has been assessed to be 20.55% of the country's geographical area. Of this, dense forest areas cover 4,16,809 sq km (12.68 %) and open forests cover 2,58,729 sq km (7.87%) (MoEF & Kalpavriksh. 2004). There have been various approaches to classifying forest ecosystems. One of the most comprehensive and detailed classifications of forests has been by Champion and Seth (1968), which is still in vogue in India. They have ecognised five major forest types: a) Tropical forests, b) Montane sub-tropical forests, c) Montane temperate forests, d) Sub-alpine forests, and, e) Alpine scrub. These are in turn classified into 16 major forest-type groups and 221 minor forest-type groups (Table 4). Besides this In India we have recorded forest areas classified as Reserve Forests (55%), Protected Forests (29%) and Unclassed Forests (16%).

Table -4. Forest Types As Classified By Champion and Seth (1968)

S.No.	Vegetation Type	Area (Million ha)	% of forest area
1	Tropical wet evergreen forest	4.5	5.8
2	Tropical semi-evergreen forest	1.9	2.5

3	Tropical moist deciduous forest	23.3	30.3
4	Littoral and swamp forest	0.7	0.9
5	Tropical dry deciduous forest	29.4	38.2
6	Tropical thorn forest	5.2	6.7
7	Tropical dry evergreen forest	0.1	0.1
8	Sub-tropical broad leaved forest	0.3	0.4
9	Sub-tropical pine forest	3.7	5.0
10	Sub-tropical dry evergreen forest	0.2	0.2
11	Montane wet temperate forest	1.6	2.0
12	Himalayan moist temperate forest	2.6	3.4
13	Himalayan dry temperate forest	0.2	0.2
14	Sub-alpine	3.3	4.3
15	Moist alpine forest	-	-
16	Alpine forest	-	-
	Total	**77**	**100**

Grasslands

Grasslands, variously called steppes, prairies, cerrados, pampas, savannahs, velds and rangelands in different parts of the world, are vegetation types with predominance of grass and grass-like species. In India, high-altitude grasslands of the Himalaya have been referred to as marg or bugiyal, and in Ladakh as tsang. Grasslands are plant communities with a more or less continuous layer of graminoids (grasses and grass-like plants), with or without a discontinuous layer of trees or shrubs. Grasslands are often associated with marked seasonality in precipitation, occurrence of fire and grazing by ungulates. Bamboo forests, though technically dominated by grasses, are not included under grasslands as they physically and in other respects resemble forests, and are usually mixed with a significant number of trees. Some research on this ecosystem was done by various workers (Singh and Gupta, 1993; Pandey and Singh, 1991; Melkania and Singh, 1989; and Singh *et al*., 1983). The grassland community builds an entirely different type of soil as compared to a forest, even when both start with the same parent material.

Since grass-plants are short-lived as compared to trees, a large amount of organic matter is added to the soil. The first phase of decay is rapid, resulting in little litter, but much humus. Humification is rapid but mineralization is slow. Consequently grassland soils may contain 5-10 times as much humus as forest soils (Odum, 1971). As of 1992, the grassland coverage of the earth's terrestrial area was about 27% (Groombridge, 1992). For India, Olson *et. al.*, (1983) put the cover of grassland and shrubland at 12% of the total landmass; however, the Planning Commission (PC 1988) estimates (MoEF & Kalpavriksh.2004) grassland coverage at 3.7%, and scientists at the Indian Grasslands and Fodder Research Institute, Jhansi, give an estimate of 3.9%, or about 120 lakh (12 million) hectares (Singh and Misri, 1993). The distribution of grasslands in India is quite uneven. For instance, in the western region, Rajasthan and Gujarat have 5.4% and 3.5% respectively of their land area under grasslands. In the eastern region, grasslands and pastures comprise less than 1% of the area, except in Sikkim, where they cover 13.3% of the land. The grasslands include such dissimilar ecosystems as the semi-arid pastures of the western part of the Deccan peninsula, the humid, semi-waterlogged tall grassland of the Terai belt, the rolling shola grasslands of the Western Ghats, hilltops, and the high-altitude alpine pastures of the Himalayas.

In India, grasses form the largest family of flowering plants. Out of an estimated 17500 species of flowering plants, about 1200 are grasses. About 360 grass taxa (almost 30%), are endemic to India. 172 endemics occur in the peninsular region, 56 in the north-east, 30 in the north-west, 5 in the western arid regions, 12 in the lower Gangetic plain, 4 in the Andaman and Nicobar Islands, and 50 endemics are spread over more than one of the above regions.

Deserts

Deserts (as distinct from desertified areas) are natural ecosystems characterized by very low rainfall (<600mm) arid and sparse presence of vegetation. Though appearing to be lifeless at first glance, deserts can harbour an astonishing and unique diversity of species, and biological communities of high conservation value. India broadly has three kinds of deserts: sandy warm desert in the far western region of Rajasthan; salt desert in the western region of Gujarat; and cold desert in the trans-Himalayan region of Ladakh in Jammu and Kashmir and Lahaul-Spiti in Himachal Pradesh.

The Great Indian Thar Desert is an important bio-region of Rajasthan comprising about 61 percent of the state's total geographical area. It is one of the most biologically and culturally diverse deserts of the world, and houses distinct and unique ecosystems, landscapes and species of plants and animals. It is characterised by geomorphic forms and landscapes such as dunes, magras, dhands and bhakars, each with a distinct ecology of its own. It is an extension of the Sahara desert, through the Arabian and Persian deserts. It extends from Punjab through Haryana and Rajasthan to Gujarat. The desert results from the dryness of the prevailing monsoon winds, which do not bring sufficient rain to keep the region moist. The desert presents an undulating surface, with high and low sand dunes separated by sandy plains and low, barren hills, or bhakars, which rise abruptly from the surrounding plains.

The Salt Desert or the Rann of Kachchh is distinguished from the Thar desert by its exceptional salinity (Rann in the local language means salt desert), caused by seasonal inundation by the sea into a vast area inland. The extraordinary intermingling of saline, marshy and coastal desert ecosystems found in the Rann is perhaps the only one of its kind in the world. The Great Rann of Kachchh and the Little Rann of Kachchh, with an area of about 16780 sq km and 5180 sq km respectively, constitute the entire Rann of Kachchh. The average altitude is about 15 m above mean sea level, and it thus appears like a table-top surface. Ecologically, it represents one of the largest seasonal saline wetland areas, having water depth ranging from 0.5 to 1.5 m. The Little Rann of Kachchh is world famous for the last remaining population of the endemic Wild Ass, and almost the entire Little Rann is covered under WAS to protect this species.

The Cold Desert, sprawled over a vast area north of the Himalayan ranges, is an ecosystem of exceptionally low temperatures (down to -75°C) and rainfall (500-800 mm annually). It forms a plateau at a height of 4,500 to 6,000 meters above mean sea level, and is encompassed by the Trans-Himalayan Biogeographic Zone (Rodgers and Panwar, 1988). This zone extends into the Tibetan plateau, to cover an area of 2.6 million sq km, from which originated the great river systems of the Indus, Sutlej, Brahmaputra and Yangtze. In India, cold deserts cover a vast area of 1, 09, 990 sq km, about 87,780 sq km in Ladakh (Kashmir), and 22,210 sq km in Lahaul-Spiti (Himachal Pradesh). Lahaul and Spiti is delimited by the Pir Panjal range, the Great Himalayan range, and the Zanskar range. The Great Himalayan range with a mean elevation of 5,500 m extends from Kunzam range to Baralacha and Pin Parvati range, separating the Chamba-Beas basin from the Sutlej-Spiti basin around Pooh, and pierced by the Sutlej at Kalpa. The Zanskar is distinguished by highly evolved life forms, including a variety of aromatic and medicinal plants, several wild relatives of domesticated plants (barley, gooseberry, garlic) and animals (four species of wild sheep and goats) and a charismatic mega-fauna, still preserved in its entirety, unlike in most other parts of the world.

Natural Aquatic Ecosystems

India has a rich variety of wetland and aquatic habitats, ranging from small streams and village ponds through large lakes and reservoirs, some of the longest rivers in the world, coastal lagoons, estuaries and backwaters, the unique Rann of Kachchh, coral reefs and mangroves, to open coastal and oceanic waters. India's wetlands can be grouped, based on salinity, into two major categories marine, and brackish or freshwater, within each of which there are several different ecosystems.

Marine Ecosystems

India has a long coastline, estimated to range between about 8000 km (Ramakrishna and Venkataraman, 2002) and 8130 km (CMFRI, 1998-99). India occupies the tenth place in terms of coastline length of all maritime countries and seventh place in terms of the extent of the Exclusive Economic Zone (2.02 million sq km) adjoining the continental region and the offshore islands. The long coastline and the tropical climate favour a multitude of coastal and offshore marine ecosystems.

Fresh and Brackish water Systems (Wetlands)

The Ramsar Convention (Ramsar, 1993) defines wetlands as 'areas of submerged or water saturated lands, both natural or artificial, permanent or temporary, with water that is static or flowing, fresh or brackish, or salty including area of marine water, the depth of which at low tide does not exceed six meters' (IUCN, 1971). The freshwater ecosystems encompass a wide spectrum of habitats covering both lentic and lotic water bodies. The former includes either temporary or permanent ponds, lakes, floodplain marshes and swamps while the latter relate to rivers and streams.

Brackish water ecosystems like the estuaries and coastal lagoons are also classified as wetlands. The natural freshwater wetlands can be broadly classified into three major categories with 15 predominant wetland types (Table 5).

Table- 5. Categories of Natural Freshwater Wetlands (Source: Scott 1989; Dugan 1990)

Type	**Nature of flow**	**Sub type**
Riverine	Perennial	i. Permanent rivers and streams, including waterfalls
		ii. Inland deltas
	Temporary	i. Seasonal and irregular rivers and streams
		ii. Riverine floodplains, including river flats, flooded river basins, seasonally flooded grasslands
Lacustrine	Permanent	i. Permanent freshwater lakes (>8 ha), including shores subject to seasonal or irregular inundation
		ii. Permanent freshwater ponds (<8 ha)
	Seasonal	i. Seasonal freshwater lakes (>8 ha), including floodplain lakes
Palustrine	Emergent	i. Permanent freshwater marshes and swamps on inorganic soil with emergent vegetation whose bases lie below the water table for at least most of the growing season
		ii. . Permanent peat-forming freshwater swamps, including tropical upland valley swamps dominated by *Papyrus* or *Typha*
		iii. Seasonal freshwater marshes on inorganic soil, including sloughs, potholes, seasonally flooded meadows, sedge marshes, and dambos
		iv. Peatlands, including acidophilous, ombrogenous, or

		soligenous mires covered by moss, herbs or dwarf shrub vegetation, and fends of all types
		v. Alpine and polar wetlands, including seasonally flooded meadows moistened by temporary waters from snowmelt
		vi. Volcanic fumaroles continually moistened by emerging and condensing water vapour
	Forested	i. Shrub swamps, including shrub-dominated fresh-water marsh, shrub carr and thickets, on inorganic soils
		ii. Freshwater swamp forest, including seasonally flooded forest, Wooded swamps on inorganic soils
		iii. Forested peat lands, including peat swamp forest

10.6 THREATS TO BIODIVERSITY

Human civilization and economic activity put pressure on aspects of biodiversity. The present rate of extinction is believed to be much higher than can be explained totally by natural causes. We must be careful to balance our needs with those of other species. There are many threats to our natural world, which include:

a. Habitat loss and destruction
b. Alteration in ecosystem composition
c. Invasive alien species
d. Over exploitation
e. Population and contamination and
f. Global climate change

10.7 BIODIVERSITY CONSERVATION

Generally, there are two basic strategies involved for the conservation purposes like in-situ and ex-situ.

10.7.1 In-situ conservation (National parks, Sanctuaries and Biosphere reserves)

In-situ conservation, the conservation of species in their natural habitats, is considered the most appropriate way of conserving biodiversity.

Conserving the areas where populations of species exist naturally is an underlying condition for the conservation of biodiversity. That's why protected areas form a central element of any national strategy to conserve biodiversity. It aims at conserving biota in their natural habitats on a holistic basis more as a system than as separate individuals. The aim is to conserve an integrated system (ecosystem) of plants, animals (wildlife) and microorganisms with its particular atmosphere, hydrosphere and lithosphere under such conditions, there are opportunities for mutualism, co-adaption and co-evolution together with the processes like mutation, recombination and natural selection which work unfettered leading to the survival of the fittest.

The most commonly referred in-situ conservation sites include:
1-Sanctuary
2-National Park
3- Biosphere reserve
4- Conservation Reserve
5- Community Reserve

1-Sanctuaries

Sanctuary is an area which is of adequate ecological, faunal, floral, geomorphological, natural or zoological significance. The Sanctuary is declared for the purpose of protecting, propagating or developing wildlife or its environment. Certain rights of people living inside the Sanctuary could be permitted. Further, during the settlement of claims, before finally notifying the Sanctuary, the Collector may, in consultation with the Chief Wildlife Warden, allow the continuation of any right of any person in or over any land within the limits of the Sanctuary (Source: http://www.moef.nic.in/downloads/public-information/protected-area-network.pdf).

2-National Parks

National Park is an area having adequate ecological, faunal, floral, geomorphological, natural or zoological significance. The National Park is declared for the purpose of protecting, propagating or developing wildlife or its environment, like that of a Sanctuary. The difference between a Sanctuary and a National Park mainly lies in the vesting of rights of people living inside. Unlike a Sanctuary, where certain rights can be allowed, in a National Park, no rights are allowed. No grazing of any livestock shall also be permitted inside a National Park while in a Sanctuary, the Chief Wildlife Warden may regulate, control or prohibit it. In addition, while any removal or exploitation of wildlife or forest produce from a Sanctuary requires the recommendation of the State Board for Wildlife, removal etc., from a National Park requires recommendation of the National Board for Wildlife (However, as per orders of Hon’ble Supreme Court dated 9th May 2002 in Writ Petition (Civil) No. 337 of 1995, such removal/ exploitation from a Sanctuary also requires recommendation of the Standing Committee of National Board for Wildlife) (Source: http://www.moef.nic.in/downloads/public-information/protected-area-network.pdf).

3-Biosphere Reserves

Biosphere reserves are areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use. They are internationally recognized, nominated by national governments and remain under sovereign jurisdiction of the states where they are located. Biosphere reserves serve in some ways as 'living laboratories' for testing out and demonstrating integrated management of land, water and biodiversity. Collectively, biosphere reserves form a world network: the World Network of Biosphere Reserves (WNBR). Within this network, exchanges of information, experience and personnel are facilitated. There are over 500 biosphere reserves in over 100 countries (Source: http://www.unesco.org/mab/doc/faq/brs.pdf).

4-Conservation Reserves

Conservation Reserves can be declared by the State Governments in any area owned by the Government, particularly the areas adjacent to National Parks and Sanctuaries and those areas which link one Protected Area with another. Such declaration should be made after having consultations with the local communities. Conservation Reserves are declared for the purpose of protecting landscapes, seascapes, flora and fauna and their habitat. The rights of people living inside a Conservation Reserve are not affected ((Source: http://www.moef.nic.in/downloads/public-information/protected-area-network.pdf).

5-Community Reserves

Community Reserves can be declared by the State Government in any private or community land, not comprised within a National Park, Sanctuary or a Conservation Reserve, where an individual or a community has volunteered to conserve wildlife and its habitat. Community Reserves are declared for the purpose of protecting fauna, flora and traditional or cultural conservation values and practices. As in the case of a Conservation Reserve, the rights of people living inside a Community Reserve are not affected (Source: http://www.moef.nic.in/downloads/public-information/protected-area-network.pdf).

Table 6. State-wise details of the Protected Areas Network of the country

S.No.	State/UT	National Parks	Wildlife Sanctuaries	Conservation Reserves	Community Reserves
1	Andhra Pradesh	6	21	0	0
2	Arunachal Pradesh	2	11	0	0
3	Assam	5	18	0	0
4	Bihar	1	12	0	0
5	Chhatisgarh	3	11	0	0
6	Goa	1	6	0	0
7	Gujarat	4	23	1	0
8	Haryana	2	8	2	0
9	Himachal Pradesh	5	32	0	0
10	Jammu &Kashmir	4	15	34	0
11	Jharkhand	1	11	0	0
12	Karnataka	5	22	2	1
13	Kerala	6	16	0	1

14	Madhya Pradesh	9	25	0	0
15	Maharashtra	6	35	1	0
16	Manipur	1	1	0	0
17	Meghalaya	2	3	0	0
18	Mizoram	2	8	0	0
19	Nagaland	1	3	0	0
20	Orissa	2	18	0	0
21	Punjab	0	12	1	2
22	Rajasthan	5	25	3	0
23	Sikkim	1	7	0	0
24	Tamil Nadu	5	21	1	0
25	Tripura	2	4	0	0
26	Uttar Pradesh	1	23	0	0
27	Uttaranchal	6	6	2	0
28	West Bengal	5	15	0	0
29	Andaman & Nicobar	9	96	0	0
30	Chandigarh	0	2	0	0
31	Dadar & Nagar Haweli	0	1	0	0
32	Lakshadweep	0	1	0	0
33	Daman & Diu	0	1	0	0
34	Delhi	0	1	0	0
35	Pondicherry	0	1	0	0
	TOTAL	**102**	**515**	**47**	**4**

(Source: http://www.moef.nic.in/downloads/public-information/protected-area-network.pdf).

Table 7. List of Biosphere Reserves, their area and location

S.No.	**Name of the Biosphere Reserve & total geographical area (Km^2)**	**Location in the State (s)/Union Territory**
1	Nilgiri (5520)	Part of Wynad, Nagarhole, Bandipur and Madumalai, Nilambur, Silent Valley and Siruvani hills in Tamil Nadu, Kerala and Karnataka.
2	Nanda Devi (5860.69)	Part of Chamoli, Pithoragarh and Almora districts in Uttarakhand.
3	Nokrek (820)	Part of East, West and South Garo Hill districts in Meghalaya.
4	Manas (2837)	Part of Kokrajhar, Bongaigaon, Barpeta, Nalbari, Kamprup and Darang districts in Assam.

5	Sunderban (9630)	Part of delta of Ganges & Brahamaputra river system in West Bengal.
6	Gulf of Mannar (10500)	India part of Gulf of Mannar extending from Rameswaram island in the North to Kanyakumari in the South of Tamil Nadu.
7	Great Nicobar (885)	Southern most island of Andaman and Nicobar Islands.
8	Similipal (4374)	Part of Mayurbhanj district in Orissa.
9	Dibru-Saikhova (765)	Part of Dibrugarh and Tinsukia districts in Assam.
10	Dehang-Dibang (5111.5)	Part of Upper Siang, West Siang and Dibang Valley districts in Arunachal Pradesh.
11	Pachmarhi (4981.72)	Part of Betul, Hoshangabad and Chhindwara districts in Madhya Pradesh.
12	Khangchendzonga (2931.12)	Part of North and West districts in Sikkim.
13	Agasthyamalai (3500.36)	Part of Thirunelveli and Kanyakumari districts in Tamil Nadu and Thiruvanthapuram, Kollam and Pathanmthitta districts in Kerala.
14	Achanakmar- Amarkantak (3,835. 51)	Part of Anuppur and Dindori districts of Madhya Pradesh and Bilaspur district of Chattisgarh.
15	Kachchh (12,454)	Part of Kachchh, Rajkot, Surendranagar and Patan districts in Gujarat.
16	Cold Desert (7,770)	Pin Valley National Park and surroundings; Chandratal & Sarchu; and Kibber Wildlife sanctuary in Himachal Pradesh.
17	Seshachalam (4755.997)	Seshachalam hill ranges in Eastern Ghats encompassing part of Chittoor and Kadapa districts in Andhra Pradesh.
18	Panna (2998.98)	Part of Panna and Chhattarpur districts in Madhya Pradesh

10.7.2-Ex-situ conservation

The ex-situ conservation approaches require collection and systematic long term storage of germ plasm outside the natural habitats of species. Normally, the following components constitute the ex-situ conservation sites.

1. Seed banks maintained at sub-freezing temperature (-20 ^{0}C),
2. Cryobanks under liquid nitrogen (-165 to -196 ^{0}C),
3. In-vitro tissue culture banks at varying degrees of temperature regimes (4 to 25 ^{0}C) and sub-culture intervals (4-24 months) depending upon individual species, DNA Banks,
4. Filed repositories,

5. Botanical Gardens,
6. Arboreta etc.

Ex-situ conservation measures can be complementary to in-situ methods as they provide an "insurance policy" against extinction. These measures also have a valuable role to play in recovery programmes for endangered species. The Kew Seed Bank in England has 1.5 per cent of the world's flora - about 4,000 species - on deposit (Source: http://www.jamaicachm.org.jm/BHS/conservation.htm)

Ex-situ conservation provides excellent research opportunities on the components of biological diversity. Some of these institutions also play a central role in public education and awareness raising by bringing members of the public into contact with plants and animals they may not normally come in contact with. It is estimated that worldwide, over 600 million people visit zoos every year.

10.8 GENE BANK

Conserving the genetic diversity of our crops, landraces and related wild species is essential to ensure future plant breeders can access this variation, especially in view of increased food demand by a growing world population and climate change.

Gene banks are repositories where biological material is collected, stored, catalogued and made available for redistribution. The main role of gene banks is to preserve genetic diversity, in the form of seeds or cuttings in the case of plants reproduced vegetatively, and subsequently make this material, together with associated information, available for future use in research and plant breeding.

Gene banks are sometimes also referred to as an ex-situ conservation facility (because biological materials are conserved outside their natural habitat). An important part of the work at gene banks is to ensure the seed collection remains alive: seeds need to be periodically checked for viability and the material regenerated to replenish the collection with fresh seed and planting materials.

Gene bank- guidelines

By now it is clear that conservation of genetic recourses is a high priority in the national or international context, as a global plan of action activity or a convention on biological diversity requirement. The National Plant Genetic Resources Programme in India has already developed elaborate guidelines for sending germplasm for long-term conservation in its gene bank, which maintains international standards and also ensure long term viability of the material conserved after due processing. It has been suggested that the following points should be check-listed after sending seeds for ex-situ conservation. The seed should be:

a. well developed and physiologically mature,
b. free from insects, weeds and disease,

c. clean and free from undesired, shriveled, immature and discolored seeds,
d. properly labeled and packed to avoid damage during transit,
e. untreated with chemicals,
f. sent to Genebank at the earliest possible (soon after harvest),
g. accompanied with minimum passport data such as name of crop, location of collection, its original identification number/name, evaluation data, other special attributes (diseases/stress resistance quality), month and year of seed harvest etc. and
h. sent in sufficient numbers.

Primarily it is suggested that the sample should contain at least 3000 seeds for conservation in case of self-pollinated crop species, which are genetically homogenous and how little morphological variation. On the other hand, 6000 seeds of cross pollinated crop species, being genetically heterogeneous, should be provided so as to give an adequate representative outlook to the accession in respect of its original population, including morphological variation of the seed lot. Seeds of landraces, wild or weedy forms and rare plant species may be provided in smaller quantities depending upon availability.

Plant genetic resource conservation in gene banks and the Indian Status

Over 2.7 million crop accessions are held in germplasm collections globally, including over 1.3 million accessions of cereals 3, 70,000 accessions of food legumes; 2,20,000 accessions of forage legumes and grasses; 1,38,000 accessions of vegetables and 74, 000 clones of root crops. Crops of major economic importance that are backed by Agricultural Research Programmes are best represented in gene banks. Keeping in view the national needs, the Department of Agricultural Research and Education and Indian Council of Agricultural Research has provided umbrella to the ex-situ and on-farm conservation of biodiversity especially agro-biodiversity. Germplasm holding of various crop plant species at different IARCs and some National gene banks are presented in Table 8 and germ plasm of Indian originated stored in different international gene banks are presented in Table 9 and 10.

Table 8. Germ Germplasm holding of various crop plant species at different IARCs and some National gene banks

Institute/Country/Gene Bank	Holdings	Institute/Country/Gene Bank	Holdings
Wheat VIR	74500	Chickpea IRCRISAT	14361
USDA	39000	ICARDA	5585
CIMMYT	31144	USA	3396
Italy	26000	India	2000
Rice IRRI	82000	Groundnut ICRISAT	11641
NSSL (USA)	18063	INDIA	6274
USDA	11230	POTATO VIR	9435
INDIA MAIZE VIR	19858	CIP	6500

CIMMYT	12500	USA	2375
NSSL (USA)	12500	INDIA MUNGBEAN	5483
YUGOSLAVIA	8000	CHINA	5483
INDIA UPLB LOS BANOS, PHILIPPINES	2500	INDIA	1850; 5736

Source: (Gautam et al., 1998)

Table 9. Germplasm of Indian-origin conserved in CGIAR gene-banks

S. No.	CGIAR Genebank	Total no. of accessions	Accessions of Indian origin	
			No.	**%**
1	International Crop Research Institute for the Semi-Arid Tropics, India	119,524	37,470	35.54
2	International Rice Research Institute, The Philippines	131,862	17,824	16.81
3	International Centre for Agricultural Research in Dry Areas, Syria	147,118	3,747	3.53
4	International Institute of Tropical Agriculture, Nigeria	27,232	2,276	8.36
5	International Livestock Research Institute, Ethiopia	20,229	501	2.48
6	Centro Internacional de Agricultura Tropical, Colombia	64,721	422	0.65
7	Centro Internacional de Mejoramiento de Maíz y Trigo, Mexico	164,320	318	0.19
8	West African Rice Development Association, Ivory Coast	26,098	299	1.15
9	*Musa* International Transit Centre, Diversity International, Belgium	1,529	54	3.53
10	Centro Internacional de la Papa, Peru	16,061	9	0.06
11	Information and Communication Division, International Center for Research in Agroforestry, Kenya	2,005	0	0
	Total	**720,699**	**62,920**	**8.73**

Table 10. Germplasm of Indian-origin conserved in major national gene-banks

S. No.	International Genebank	Total no. of accessions	Accessions of Indian-origin	
			No.	%
1	USDA Genebanks, USA	625,112	22,582	3.61
2	N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry, Russia	346,415	8,145	2.35
3	Asian Vegetable Research and Development Center, Taiwan	60,883	4,729	7.77
4	Leibniz Institute of Plant Genetics and Crop Plant Research, Germany	137,010	2,233	1.63
5	Department of Applied Genetics, John Innes Centre, Norwich Research Park, UK	26,669	1,714	6.43
6	Plant Breeding and Acclimatization Institute, Poland	67,980	428	0.62
7	Millennium Seed Bank Project, Seed Conservation Department, Royal Botanic Garden, Kew, UK	46,689	335	0.72
8	Division of Genetics and Plant Breeding, Research Institute of Crop Production, Czech Republic			

(**Source**: Indian Plant Germplasm on the Global Platter: An Analysis Sherry R. Jacob,[1] Vandana Tyagi,[2] Anuradha Agrawal,[3] Shyamal K. Chakrabarty,[4] and Rishi K. Tyagi[1,*] LoS One. 2015; 10(5): e0126634. Published online 2015 May 14.doi: 10.1371/journal.pone.0126634.)

10.9 NATIONAL BUREAU OF PLANT GENETIC RESOURCES

History

Indian interest and abiding concern in the collection and utilization of plant genetic resources dates back to the early decades of this century (Howard and Howard, 1910), though botanical accounts on available flora and the economic plants/products had been documented much earlier (Hooker, 1872-97; Watt, 1889-93). However, it was late Dr. B.P. Pal who truly focused attention on the use of germplasm variability in crop improvement in national context. The publication of his paper, ‘The search for new genes', in fact, paved the way for augmenting genetic diversity for use in plant breeding (Pal, 1937; Pal and Singh, 1943). It was primarily due to his foresight and wisdom that a nucleus Plant Exploration and Collection Unit was established in 1946 in the Division of Botany at the Indian Agricultural Research Institute, New Delhi. This unit became a regular wing in 1956 that was raised to the status of a Division of Plant Introduction in 1961. The late Dr. Harbhajan Singh dedicated his entire services to operate and boost these activities from the beginning and particularly so during the 1960s-1970s. (Singh and Hardas, 1970; Singh, 1970). Dr. M.S. Swaminathan and Dr. A.B. Joshi further strengthened the foundations of these activities. To serve the needs of the ICAR Crop Research Institutes, All India Coordinated Crop Improvement Projects and State Agricultural Universities, the Indian Council of Agricultural Research created a separate organization named as National Bureau of Plant Genetic Resources (NBPGR) in 1976 along with two other Bureaus concerned with animal and fish genetic resources.

NBGPR and its activities

NBPGR's activities have grown rapidly since 1976. It is a service-oriented national institute with a component of basic research for improving quality and efficiency of its services. It has five major Divisions, namely, Division of Plant Exploration and Collection, Division of Germplasm Exchange, Division of Plant Quarantine, Division of Germplasm Evaluation and Division of Germplasm Conservation. In addition, there is a DBT funded National Facility for Plant Tissue Culture Repository. The Bureau also has 12 Regional Stations/Base Centres/Quarantine Stations/Experimental Farms located in different agro-climatic zones. In addition, several All India Coordinated Crop Improvement Projects on Medicinal and Aromatic Plants, cluster bean, and under-utilized and under-exploited plants are also located at the Bureau. Primary objectives of the Bureau are to:

1. Organize and conduct plant exploration and germplasm collection activities in India and abroad.
2. Undertake and coordinate the supply/introduction/exchange of plant genetic resources for research purpose within India and abroad.
3. Conduct plant quarantine examination of plant materials introduced by the Bureau for pests and pathogens; treat and salvage infested/infected material and carry out research on plant quarantine/seed-health problems.
4. Conduct, monitor and coordinate all activities concerning germplasm conservation in national base and active collections.
5. Characterize, evaluate and document available germplasm collections and coordinate these activities at the Regional Stations and other collaborating Institutes with a view to preparing proper inventories and catalogues of such resources.
6. Develop and operate the National PGR Database for documentation and retrieval of information on plant genetic resources held by the Bureau and all other collaborating institutes/centres.
7. Conduct training programmes on different aspects of genetic resources activities at national and international levels.
8. Develop and implement work-plans concerning PGR activities based on memoranda of understanding under bilateral and international agreements.

In order to fulfill its national mandate, the Bureau maintains links with all crop-based institutes/national research centres of the Indian Council of Agricultural Research, State Agricultural Universities and the network of All India Co-ordinated Crop Improvement Projects. In addition, the Bureau maintains effective links with more than seventy countries as well as different crop-based international institutes under the CGIAR system including, the IBPGR.

The Exploration Division of NBPGR develops advance perspective plans for germplasm collection in collaboration with other cooperating institutes/centres. More than 80,000 accessions of indigenous cultivars and their wild relatives have already been collected through over 300 crop-specific and region-specific explorations (Table 6). These represent wide variability in crops like wheat, maize, rice, minor millets, cucurbits, okra, eggplant, tuber crops, jute, cotton, ginger, sugarcane, mango, banana, jujube, citrus, black pepper, turmeric, medicinal plants and forages, besides many others. The areas already explored include the North-eastern region, North-Western Himalayas, drier western plains, central India and the eastern and western peninsular tracts. Indigenous collections have been further enriched by importing over 9, 00,000 samples from more than 70 countries through specific requests and exchange (Table 7). Diverse germplasm has thus been introduced from different international crop-based institutes/centres like IRRI, Philippines; CIMMYT, Mexico; ICARDA, Syria; CIP, Peru; CSIRO, Australia; VIR, USSR; USDA, USA; AVRDC, Taiwan; INTSOY, USA; ICRISAT, India, besides, the FAO and IBPGR.

Plant quarantine facility at the Bureau has helped in ensuring that insect pests, pathogens and obnoxious weeds do not enter the country along with seed and other propagating materials. Well equipped laboratories of Plant Pathology, Virology, Nematology and Entomology work hand-in-hand to salvage the infected/infested materials using techniques, such as mechanical cleaning, washing, fumigation, X-ray radiography, hot water treatment, acid seed treatment, pesticidal seed treatment, dips and sprays, etc. A large number of important exotic plant pests, nematodes and pathogens have been intercepted. A recent case is that of the groundnut stripe virus intercepted by the Hyderabad Station of NBPGR in collaboration with ICRISAT.

The Seed Repository of the National Gene Bank at NBPGR Headquarters, New Delhi, conserves genetic resources of orthodox (desiccation-tolerant) agri-horticultural crop plants in the form of seed under controlled conditions of temperature and seed moisture. Two types of cold storage vaults are available: (i) medium-term storage facility kept at + 4° C and 35 percent RH, and (ii) long-term storage vaults (2 units of 100 m^2 each and 2 of 176 m^2 each) maintained at-20° C. The repository has a fully equipped seed testing laboratory and other ancillary facilities. Over 1, 35, 000 accessions of various crop plants are currently stored in the repository (Table 11) and its present storage capacity is about two lakh (0.2 million) accessions. Protocols have also been developed for making the plant germplasm collections disease-free through tissue culture techniques and ensuring their safety under *in-vitro* storage. Work has been in progress on crops, such as yams, *Coleus*, ginger, *Musa* and citrus. Experimental work has also progressed for storing seeds at -196°C in cryopreservation tanks using liquid nitrogen.

Table 11. National gene bank in operation at NBPGR (germplasm kept in long-term storage

Crop groups	No. of accessions
Cereals	34,697
Pulses	21,510
Millets and minor millets	12,850
Oilseeds	12,621
Vegetables	3,635
Fibre crops	2,609
Narcotics	665
Medicinal and aromatic plants	138
Pseudo cereals (miscellaneous crops)	653
Improved (named) varieties	302
Voucher specimens of exotics	19,178
Reference samples of indigenous collection	27,000
Total holdings	**1,35,858**

The Bureau is also the lead institute to impart training in all facets of PGR activities. It has organized international/regional training programmes for the South and South-East Asia region with IBPGR support. It has also conducted regular short duration trainings at the national level and a Summer Institute sponsored by ICAR. This activity has been further accelerated now (from 1990) with national training programmes conducted by NBPGR in plant exploration and collection, tissue culture and cryopreservation techniques, medium and long-term storage of seed materials, exchange of germplasm and plant quarantine methods, and computer appreciation related to PGR documentation. The emphasis is on training of the concerned PGR scientists from ICAR crop institutes and other interested research centres in public institutions and universities with a view to producing more resource personnel in this field. The NBPGR is also the information dissemination organization on PGR activities. It regularly publishes Research Highlights, Annual Reports, Newsletter (quarterly) and the Plant Introduction Reporter (quarterly). It has so far published well over 400 research papers, reports, brochures, bulletins, inventories, catalogues, books, proceedings of seminar/symposia, etc. with bearing on conservation and scientific management of plant genetic resources. This has helped in creating awareness and know-how among the scientific community as well as public and private organizations.

10.10 ENVIRONMENTAL STATUS OF PLANT BASED ON INTERNATIONAL UNION FOR CONSERVATION OF NATURE (IUCN)

International Union for Conservation of Nature (IUCN): The International Union for Conservation of Nature and Natural Resources (IUCN), with its headquarters are in Gland, Switzerland, is an international organization working in the field of nature conservation and sustainable use of natural resources. It is involved in data gathering and analysis, research, field projects, advocacy, and education. IUCN's mission is to "influence, encourage and assist societies throughout the world to conserve nature and to ensure that any use of natural resources is equitable and ecologically sustainable". It plays a role in the implementation of several international conventions on nature conservation and biodiversity. IUCN is the world's main authority on the conservation status of species. The IUCN Red List of Threatened Species The IUCN Red List of Threatened Species (also known as the IUCN Red List or Red Data List), Established in 1964, has evolved to become the world's most comprehensive information source on the global conservation status of animal, fungi and plant species. It is a critical indicator of the health of the world's biodiversity. It uses a set of criteria to evaluate the extinction risk of thousands of species and subspecies. These criteria are relevant to all species and all regions of the world. Far more than a list of species and their status, it is a powerful tool to inform and catalyze action for biodiversity conservation and policy change, critical to protecting the natural resources we need to survive. It provides information about range, population size, habitat and ecology, use and/or trade, threats, and conservation actions that will help inform necessary conservation decisions. The IUCN Red List is produced by the Red List Partnership: Bird Life International; Botanic Gardens Conservation International; Conservation International; International Union for Conservation of Nature (IUCN); Nature Serve; Microsoft; Royal Botanic Gardens, Kew; Sapienza University of Rome; IUCN Species Survival Commission; Texas A&M University; Wildscreen; and Zoological Society of London.

IUCN Categories of Threatened Species

The International Union for Conservation of Nature (IUCN) is a leading international organization working in the field of nature conservation and sustainable use of natural resources. It was established in 1948 and evolved as world‘s largest environment network and plays a key role to save biodiversity at global level. IUCN includes over 1400 members of both governmental and non-governmental organizations. The IUCN publishes IUCN Red List of Threatened Species. In 1969, India became a State Member of IUCN. The Office of IUCN India located in New Delhi was established in 2007. The IUCN Red List of Threatened Species, founded in 1964, is the world‘s most comprehensive inventory of the global conservation status of biological species. As per the relative risk of extinction, the red data list contains 7 categories. There are categories given below along with some Indian species.

Extinct (EX) – No known individuals remaining

Extinct in the Wild (EW) – Known only to survive in captivity, or as a naturalized population outside its historic range
Critically Endangered (CR) – Extremely high risk of extinction in the wild
Endangered (EN) – High risk of extinction in the wild.
Vulnerable (VU) – High risk of endangerment in the wild
Near Threatened (NT) – Likely to become endangered in the near future
Least Concern (LC) or Lowest risk - Does not qualify for a more at risk category.

Red Data Book

The Red Data Book is a public document that is created for recording endangered and rare species of plants, animals, fungi as well as some local subspecies that are present in a particular region.

The Red Data Book helps us in providing complete information for research, studies and also for monitoring the programs on rare and endangered species and their habitats. This book is mainly created to identify and protect those species which are on the verge of extinction.

History of the Red Data Book

The name of this book has its origins in Russia, it was originally known as the Red Data Book of the Russian Federation or the RDBRF. The book was based on research conducted between 1961 and 1964 by biologists in Russia. Hence, it is also called the Russian Red Data Book. Currently, the International Union for Conservation of Nature maintains the Red Data Book. IUCN is the world‵s most detailed inventory centre of the global conservation status of biological species. The International Union for Conservation of Nature (IUCN) was founded in 1948 with an aim to maintain a complete record of every species that ever lived. The Red Data Book contains the complete list of threatened species. The main aim behind this documentation is to provide complete information for research and analysis of different species.

The Red Data Book contains colour-coded information sheets, which are arranged according to the extinction risk of many species and subspecies.

- Black represents species that are confirmed to be extinct.
- Red represents species that are endangered
- Amber for those species whose status is considered to be vulnerable
- White is assigned for species that are rare
- Green for species that were formerly endangered, but their numbers have started to recover
- Grey coloured for the species that are classified as vulnerable, endangered, or rare but
- sufficient information is not available to be properly classified.
- In a nutshell, the Red Data Book indexes species as:
- Threatened
- Not threatened
- Unknown

Furthermore, The Red Data Book also has information as to why a species has become extinct along with the population trends and the extent of its range (distribution).

Advantages of the Red Data Book

- It helps in identifying all animals, birds and other species about their conservation status.
- It is used to evaluate the population of a particular species.
- The data available in this book can be used to evaluate the taxa at the global level.
- With the help of this book, we can estimate the risk of taxa becoming globally extinct.
- Provides a framework or guidelines for implementing protective measures for endangered species.

Disadvantages of the Red Data Book

- The information available in the Red Data Book is incomplete. Many species, both extinct and extant are not updated in this book.
- The source of the book‘s data has been speculated and has been mired in controversy.
- This book maintains the complete record of all animals, plants, other species but it has no information about the microbes.

Red Data Book of India

Red Data Book of India includes the conservation status of animals and plants which are endemic to the Indian subcontinent. The data for this book is provided through surveys which are conducted by the Zoological Survey of India and the Botanical Survey of India under the guidance of the Ministry of Environment, Forest and Climate Change.

Red Book Data: List of Threatened Flora and Fauna in India

- Sumatran Rhinoceros (*Dicerorhinus sumatrensis*)
- Hangul deer (*Cervus canadensis hangul*)
- Himalayan Brown or red Bear (*Ursus arctos isabellinus*)
- Pygmy Hog (*Porcula salvania*)
- Andaman White-toothed Shrew (*Crocidura andamanensis*)
- Kondana Soft-furred Rat (*Millardia kondana*)
- Elvira Rat or Large Rock Rat (*Cremnomys elvir*).
- Namdapha Flying Squirrel (*Biswamoyopterus biswasi*)
- Malabar large-spotted civet(*Viverra civettina*)
- Red panda (*Ailurus fulgens*)
- Asiatic wild dog (*Cuon alpines*).
- Wild ass (*Equus hemionus*)
- Brow-antlered deer(*Rucervus eldii*)
- Golden Langur (*Trachypithecus geei*)

- White-bellied Musk Deer(*Moschus leucogaster*)
- Hispid hare/ Assam rabbit (*Caprolagus hispidus*)
- Indian hog deer (*Axis porcinus*)
- Lion tailed macaque (*Macaca silenus*)
- Tibetan antelope (*Pantholops hodgsonii*)
- Nilgiri langur (*Trachypithecus johnii*)
- Nilgiri tahr (*Nilgiritragus hylocrius*)
- Ganges river dolphin (*Platanista gangetica*)

Threatened flora species are:

- Milkwort (*Polygala irregularis*)and Environmental Conservation- II
- Bird's foot (*Lotus corniculatus*)
- Assam catkin yew (*Amentotaxus assamica*)
- Moa, skeleton, fork fern, and whisk fern (*Psilotum nudum*)
- Umbrella tree, kudai vel (Tamil) (*Acacia planifrons*)
- Indian mallow, thuthi (Tamil) and athibalaa (Sanskrit) (*Abutilon indicum*)
- Ebony tree (*Diospyros celibica*)
- Malabar lily (*Chlorophytum malabaricum*)
- Spider wort (*Belosynapsis vivipara*)
- Malayuram, Malavuram (*Pterospermum reticulatum*)
- Jeemikanda (Gujarat) (*Ceropegia odorata*)
- Musli (*Chlorophytum tuberosum)*

10.11 GLOBAL BIODIVERSITY HOTSPOTS

Globally, at as present the 35 biodiversity hotspots (Table 12) that cover only 17.3% of the Earth's land surface are characterized by both exceptional biodiversity and considerable habitat loss (Myers et al., 2000). More precisely, hotspots maintain 77% of all endemic plant species, 43% of vertebrates (including 60% of threatened mammals and birds), and 80% of all threatened amphibians (Mittermeier et al., 2011; Williams et al., 2011).

Table-12 Biodiversity hotspots from 1988 to present

Source: Modified from: Mittermeier et al. (2011).

Myers (1988)	Myers (1990)	Myers et al. (2000)	Mittermeier et al. (2004)	2011 Revision
Uplands of Western Amazonia Western Ecuador	Uplands of Western Amazonia Western Ecuador	Tropical Andes[a]	Tropical Andes	Tropical Andes

Colombian Choco	Colombian Choco	Choco/Darien/western Ecuador[b]	Tumbes-Choco-Magdalena	Tumbes-Choco-Magdalena
Atlantic Coast Brazil	Atlantic Coast Brazil	Atlantic Coast Brazil	Atlantic Forest	Atlantic Forest
		Brazilian Cerrado	Cerrado	Cerrado
	Central Chile	Central Chile[a]	Chilean Winter Rainfall and	Chilean Winter
Rainfall			Valdivian Forest	and Valdivian Forest
		Mesoamerica	Mesoamerica	Mesoamerica
			Madrean Pine-Oak Woodlands	Madrean Pine-Oak Woodlands
		Caribbean	Caribbean Islands	Caribbean Islands
	California Floristic Province	California Floristic	California Floristic Province	California
Floristic		Province		Province
	Ivory Coast	Guinean Forest of West	Guinean Forest of West	Guinean Forest of
West		Africa[a]	Africa	Africa
	Cape Floristic Region	Cape Floristic Province	Cape Floristic Region	Cape Floristic
Region				
		Succulent Karoo	Succulent Karoo	Succulent Karoo
			Maputaland-Pondoland-Albany	Maputaland-Pondoland-Albany
	Tanzania	Eastern Arc and Coastal	Eastern Afromontane[d]	Eastern Afromontane
Forest of		Tanzania/Kenya		
			Coastal Forests of Eastern Africa[d]	Coastal Forests of Eastern Africa
			Horn of Africa	Horn of Africa
Eastern Madagascar	Eastern Madagascar	Madagascar and Indian Ocean Islands	Madagascar and Indian Ocean Islands	Madagascar and Indian Ocean Islands
		Mediterranean Basin	Mediterranean Basin	Mediterranean Basin
		Caucasus	Caucasus	Caucasus
			Irano-Anatolian	Irano-Anatolian
			Mountains of Central Asia	Mountains of Central Asia
	Western Ghats in India Southwestern Sri Lanka	Western Ghats and Sri Lanka[b]	Western Ghats and Sri Lanka	Western Ghats and Sri Lanka
		Mountains of South-Central China	Mountains of South-Central China	Mountains of South-Central China
			Indo-Burma	Indo-Burma
Eastern Himalayas	Eastern Himalayas	Indo-Burma[e]	Himalaya[f]	Himalaya
Peninsular Malaysia	Peninsular Malaysia			
Northern Borneo	Northern Borneo	Sundaland[b]	Sundaland	Sundaland
		Wallacea	Wallacea	Wallacea
Philippines	Philippines	Philippines	Philippines	Philippines
			Japan	Japan
	Southwest Australia	Southwest Australia[a]	Southwest Australia	Southwest Australia
			Forests of East Australia[g]	Forests of East Australia
			East Melanesian Islands	East Melanesian Islands
		New Zeeland	New Zeeland	New Zeeland
New Caledonia	New Caledonia	New Caledonia	New Caledonia	New Caledonia
		Polynesia-Micronesia	Polynesia-Micronesia	Polynesia-Micronesia

a. Expanded.

b.Merged and/or expanded.

c. Expanded to include Coastal Forests of Tanzania and parts of Kenya.

d The Eastern Arc and Coastal Forests of Tanzania/Kenya hotspots was split into the Eastern

Afromontane hotspot (the Eastern Arc Mountains and Southern Rift, the Albertine Rift, and the Ethiopian Highlands) and Coastal Forests of Eastern Africa (southern Somalia south through Kenya, Tanzania and Mozambique).

e Eastern Himalayas was divided into Mountains of South-Central China and Indo-Burma, the latter of which was expanded.

f .The Indo-Burma hotspot was redefined and the Himalayan chain was separated as a new Himalayan hotspot, which was expanded. g The Forests of Eastern Australia the 35th biodiversity hotspot.

10.12 INDIA AS MEGA-BIODIVERSITY COUNTRY

India is exceptionally rich in biodiversity and is one of the twelve mega diversity centres of the world. With 10 biogeographic zones and 25 biotic provinces, all major ecosystems are represented. India is a land mass of nearly 33 lakh sq km with a coastline of 7,616 km and 14 different types of climatic forests and the total forest coverage in India is about 6,50,000 sq km. The diverse physical features and climatic situations have formed ecological diverse habitats like forests, grasslands, wetlands, coastal and marine ecosystems and desert ecosystems, which harbor and sustain immense biodiversity. Biogeographically, India is situated at the tri-junction of three realms - Afro-tropical, Indo-Malayan and Paleo-Arctic realms, and therefore, has characteristic elements from each of them. This assemblage of three distinct realms makes the country rich and unique in biological diversity. Sinology

India is the home land of 13,000 species of flowering plants, 20,000 species of fungi, 50,000 species of insects, 65,000 species of fauna including 2000 species of birds, 350 mammals and 420 of reptiles. It covers nearly 7% of world's flora and 6.5% of world's fauna of which 33 % flora and 62% fauna are endemic. India has over 30 National parks that constitute about 1% of the landmass and 441 sanctuaries that constitute 3.5% of the area. India is a home of over 35,000 tigers and the umbrella of project tiger 23 specially demarcated project tiger reserves covering 33,000 sq.km representing different climatic forests are spread across the country. The country is also one of the 12 primary centres of origin of cultivated plants and domesticated animals. It is considered to be the homeland of 167 important plant species of cereals, millets, fruits, condiments, vegetables, pulses, fibre crops and oilseeds, and 114 breeds of domesticated animals.

India has a rich and varied heritage of biodiversity, encompassing a wide spectrum of habitats from tropical rainforests to alpine vegetation and from temperate forests to coastal wetlands. **India figured with two hotspots** - the Western Ghats and the Eastern Himalayas - in an identification of 18 biodiversity hotspots carried out in the eighties. Recently, Norman Myers and a team of scientists have brought out an **updated list of 25 hotspots**. In the revised classification, the 2 hotspots that extend into India are The Western Ghats/Sri Lanka and the Indo-Burma region (covering the Eastern Himalayas); and they are included amongst the top eight most important hotspots. In addition**, India has 26 recognised endemic centres** that are home to nearly a third of all the flowering plants identified and described to date.

Of the estimated 5–50 million species of the world's biota, only 1.7 million have been described to date, and the distribution is highly uneven. About seven per cent of the world's total land area is home to half of the world's species, with the tropics alone accounting for 5 million. India contributes significantly to this latitudinal biodiversity trend. With a mere 2.4% of the world's area, India accounts for 7.31% of the global faunal total with a faunal species count of 89,451 species. Some salient features of India's biodiversity have been mentioned below.

1. India has two major realms called the Palaearctic and the Indo-Malayan, and three biomass, namely the tropical humid forests, the tropical dry/deciduous forests, and the warm desert/semi-deserts.
2. India has ten biogeographic regions including the Trans-Himalayan, the Himalayan, the Indian desert, the semi-arid zone(s), the Western Ghats, the Deccan Peninsula, the Gangetic Plain, North-East India, and the islands and coasts.
3. As of date, there are 911 properties under the World Heritage List, which cover 711 cultural sites, 180 natural sites and 27 mixed properties encompassing 152 countries, including India. India is one of the 12 centres of origin of cultivated plants.
4. India's first two sites inscribed on the list at the Seventh Session of the World Heritage held in 1983 were the Agra Fort and the Ajanta Caves. Over the years, 27 more sites have been inscribed, the latest site inscribed in 2012 being the Western Ghats. Of these 29 sites, 23 are cultural sites and the other six are natural sites. A tentative list of further sites/properties submitted by India for recognition includes 33 sites.
5. India has 17 biosphere reserves, and 19 Ramsar wetlands. Amongst the protected areas, India has 102 national parks and 490 sanctuaries covering an area of 1.53 lakh sq km.
6. The wildlife sanctuaries in India are home to around two thousand different species of birds, 3500 species of mammals, nearly 30000 different kinds of insects and more than 15000 varieties of plants.

The endemism of Indian biodiversity is high. About 33% of the country's recorded flora are endemic to the country and are concentrated mainly in the North-East, Western Ghats, North-West Himalaya and the Andaman and Nicobar islands. Of the 49,219 plant species, 5150 are endemic and distributed into 141 genera under 47 families corresponding to about 30% of the world's recorded flora, which means 30% of the world's recorded flora are endemic to India. Of these endemic species, 3,500 are found in the Himalayas and adjoining regions and 1600 in the Western Ghats alone. About 62% of the known amphibian species are endemic with the majority occurring in the Western Ghats. Nearly 50% of the lizards of India are endemic with a high degree of endemicity in the Western Ghats. India is a centre of crop diversity - the homeland of 167 cultivated species and 320 wild relatives of crop plants.

Corals reefs in Indian waters surround the Andaman and Nicobar Islands, the Lakshadweep Islands, and the Gulf areas of Gujarat and Tamil Nadu. They are nearly as rich in species as tropical evergreen forests.

India's record in agro-biodiversity is equally impressive. There are 167 crop species and wild relatives. India is considered to be the centre of origin of 30,000-50,000 varieties of rice, pigeon-pea, mango, turmeric, ginger, sugarcane, gooseberries etc and ranks seventh in terms of contribution to world agriculture.

10.13 ENDEMISM

The idea of endemism dates back to more than 200 years, and has been employed, as it is actually understood, by de Candolle. Since then, the concepts of endemicity and areas of endemism have been widely discussed. Some problems around these concepts emerge from the diverse uses and interpretations given to them in literature (Harold and Moii). Although differences between diverse uses as regards connotations could seem minor, the lack of precision in the definition of these concepts hinders an unambiguous interpretation and causes confusion. Additionally, numerous expressions, such as “generalized track”, “track”, “biotic element”, “centers of endemicity”, “units of co-ocurrence”, among others, are commonly used as synonyms of area of endemism. Although basically related with the term “areas of endemism”, these concepts refer to different patterns of distribution and are defined on different theoretical grounds.

Brief Review of ideas on Endemism

Naturalists and Botanists have recognized the existence of rare or endemic plants for centuries. Cain (1944) ascribes the origin of the world endemic as it is applied to the distribution of organism to A. De Candolle (1855) the great voyages of discovery from the seventeen through nineteenth centuries brought to light countless rare and endemic taxa. Linnaeus’s *Species Plantarum* of 1753 lists no rarities from different areas but only recorded some local endemic species, some of them are still rare and some are extinct. Adolph Engler (1882) appears to be the originator of the dichotomy of old Vs new endemics, which has been extensively by other plant geographers ever since Stebbins (1942) and Stabbins and Major (1965). Willis (1922) quantified the idea of the youthful endemic with his J-shaped or hollow curves; they became the backbone of his controversial and largely discredited theory of age and area. Stebbins (1942) provided a genetical explanation for the epibiotic or relictual endemic. Stebbins and Major (1965) recast Cain’s two categories as paleoendemism and neoendemism. These authors point to persistent defects in the new vs old endemic dichotomy. Stabbins and Major based their classification upon the way in which narrow endemics have achieved their restricted distribution, since this varies among species; this system was also proposed by Favarger and Contandriopouplos (1961). Stebbins and Major’s system incorporates the age of endemic, its systematic position, and cytological data. In groups of related species, diploids are older than derivative low polyploids, while both high polyploids and diploids are paleoendemics. Endemics with more than one disjunct population are most likely (paleoendemics), while endemics confined to a single population can be either paleoendemics or neoendemics. Stebbins and Major use the ploidal level and its modes of origin both to categories endemics and to explain their origin. Paleoendemics are ancient vestiges of taxa that were once more widespread. Their present relictual status is preseumably the result of the increasing constriction of their specialized habitats over time. The neoendemics, on the other hand, are recent in origin, have just split off from a parental entity, and may be poised for a further expansion of their ranges and gene pools. *Plantago cordata* (Meagher et al., 1978) and *Stephanomeria malheurensis* (Gottlieb, 1979) demonstrate that both paleoendemics and neoendemics indeed occur, but we currently have no way to evaluate their relative proportion in floras. Between the two extremes in age of endemics, there are, of course, endemics of intermediate age; they remain narrow endemics, confined to a restricted, local habitat. Recent reviews agree that there are multiple causes of rarity and endemism. Neither genetics, ecology, nor history alone will suffice to explain the origin of endemic taxa. Moreover, the interplay among various casual factors will vary in intensity, depending on the particular taxon under scrutiny. Stebbins (1942) proposes the gene pool/niche interaction theory to explain origin or rarity and endemism. His notion is grounded on the assumption of multiple causation:

"According to this theory, the primary cause of localized of endemic distribution patterns is adaptation to a combination of ecological factors that are themselves localized. Factors of soil texture or chemical composition are the most common but by no means the only ones……… Next to climate and edaphic factors, those inherent in the gene pool of the population are of critical importance. They include the total amount of variability, the amount of variability that can be released at any one time, and the amount of variation that can be generated with respect to those particular characteristics that affect most strongly the establishment of new populations (Stebbins, 1980).

Endemism is found on all land masses of the world, both continent and islands and in all major biomes. More curious is the well-known fact, first identified by Charles Darwin that the quantity and quality of endemism differ among the major geographic, topographic and vegetation types. For examples, while species number is smaller for island than for areas of comparable size on continents, the islands have higher proportions of endemics. Most oceainc islands are far richer in endemics than isalnd, their endemics would perforce to be narrowly distributed i.e., true rarities.

Endemic plants also are distributed unevenly across the land areas of the world. Some places, like mountains and islands, are rich in endemics, while boreal and arctic regions are relatively poor in them. Many parts of the world are well-known centres of endemics: California, The European Alps, The Mediterrnean region, Alpine regions of Central Africa, New Caledonia, Hawaii, the Cape region of South Africa, and the Sino-Himalayan region. Nonetheless, examples of narrow endemics abound in nearly all floras.

Generally Endemism is a unique phenomenon in the geographical distribution of species. Endemic species are restricted to extremely small ranges, even a single rock out crop. The environmental factors and topography play an important role in speciation. Especially in the

Himalayan context, high mountain peaks and deep river valley, together with the environmental factors, play important role in the range restriction/speciation.

10.14 SUMMARY

This Module provides a global overview of the different definitions of biodiversity proposed by different workers from time to time, various concepts behind the Conservation of Biological Diversity in general and particular as per the Convention of Biological Diversity (CBD), and various types of ecosystems and their percentage share of faunal and floral diversity of the globe as well as India. Further, various levels of biodiversity, further concept and major themes within the biodiversity were also discussed for the better understanding of the students. Also an attempt has been made to discuss various ecosystem diversity of the India including Agricultural Ecosystem and their share in Indian Biodiversity. Further, threats also pose a serious problem in the conservation of the biodiversity therefore different kinds of threats responsible for the depletion of the biodiversity was also discussed. Current hypothesis with all clarifications regarding the loss of biodiversity was also presented in this module.

This Module also provides comprehensive information about need of the conservation and also tries to explain why conservation of biodiversity is necessary. Explanatory notes on the various conservation methods like ex-situ and in-situ were also discussed in details along with the examples of the said methods (In-situ: National Parks, Wildlife Sanctuaries, Biosphere Reserves, Conservation Reserve and Community Reserves and Ex-situ: Seed Banks, Cryobanks, Field repositories, Botanical Gardens, and Arboreta along with suitable definitions and list of all categories). It also helps to understand the concepts behind Protected Areas Network and its different categories. In this module attempt was also made to discuss history of Plant Genetic Resources and details in different Gene Banks and the responsibilities of the organizations involved in such types of work. Further, this module also discussed history; role and importance of National Bureau of Plant Genetic Resources (a nodal agency of conservation in India).

10.15 GLOSSARY

CBD: Convention on Biological Diversity

WCMC: World Conservation Monitoring Centre

Genes: The basic biological unit of heredity. Genes of an individual belonging to the same species are similar and genes control the characteristics of particular species.

Species: A species is often defined as a group of individuals that actually or potentially interbreed in nature. In this sense, a species is the biggest gene pool possible under natural conditions.

Ecosystem: An ecosystem includes all of the living things (plants, animals, and microorganisms in a given area, interacting with each other, and also with their non-living environments

FSI: Forest Survey of India

IUCN: International Union for Conservation of Nature and Natural Resources

10.16 SELF ASSESSMENT QUESTIONS

10.16. 1 Objective type questions:

1- Who coined the term biodiversity?
(i) Lovejoy (ii) E.P. Odum
(iii) S.K. Jain (iv) E.O. Wilson

2- How many levels Biodiversity have?
(i) Four (ii) Five
(iii) Three (iv) Two

3- India constitutes …………….. % of world's flora?
(i) 2.4 (ii) 3.4
(iii) 4.4 (iv) 1.4

4- As at present how many Global Biodiversity Hotspots we have?
(i) 35 (ii) 40
(iii) 33 (iv) 34

5- How many forest types we have in India?
(i) 10 (ii) 16
(iii) 14 (iv) 6

6- The Great Indian Thar Desert is an important bio-region of …………………?
(i) Uttar Pradesh (ii) Rajasthan
(iii) Uttarakhand (iv) Jammu and Kashmir

7- The Ramsar Convention is for…………………
(i) Wetlands (ii) Forests
(iii) Grasslands (iv) Alpine regions

8- ……………..% flora of India is endemic?
(i) 35 (ii) 29
(iii) 46 (iv) 28

9- India is the home land of ……………………flowering plants.
(i) 13,000 (ii) 15,000
(iii) 70000 (iv) 5000

10- From the point of view of natural vegetation and wildlife, India belongs to which of the following categories?
(i) One of the twelve mega biodiversity countries of the world
(ii) The richest wildlife zone in the world
(iii) The country with the greatest forest cover
(iv) A country lacking in biodiversity cover

10.16.1 Answers Key:

1-(i); 2-(iii); 3-(i); 4-(i); 5-(ii); 6-(ii); 7-(i); 8-(ii); 9-(i); 10-(i).

10.17 REFERENCES

- Lovejoy, T. E. (1980). The Global 2000 Report to the President (G. O. Barney, ed.), Vol. 2, The Technical Report, pp. 327–332. Penguin, New York.
- Wilson, E. O., and Peter, F. M. (1988). Biodiversity. National Academy Press, Washington, D.C.
- CBD. (1992). Convention of Biological Diversity (CBD), United Nations.
- D.L. Perlman and G. Andelson. (1997). Biodiversity: exploring values and priorities in conservation. Blackwell Sciences United States of America
- Fiedler, P. L., and Jain, S. K. (1992). Conservation Biology: The Theory and Practice of Nature Conservation, Preservation and Management. Chapman and Hall, New York
- Hunter, M. L., Jr. (1996). Fundamentals of Conservation Biology. Blackwell Science, Cambridge, Massachusetts
- McNeely, J. A., Miller, K. R., Reid, W. V., Mittermeier, R. A., and Werner, T. B. (1990). Conserving the World's Biological Diversity. International Union for Conservation of Nature and Natural Resources/World Resources Institute/Conservation International/World Wildlife Fund–U.S./World Bank, Gland, Switzerland/Washington, D.C.
- Z. X. Chen, S. Y. Chen. (1992). Nematology: advances and perspectives, Vol. 1 By, Donald Ward Dickson p 439.). U.S. National Research Council.
- Michael J. Jeffries. (1997). Biodiversity and Conservation. 2nd edition. Routlegde Taylor and Francis Group. London and NY.
- Rodgers W.A., Panwar H.S., Mathur V.B. 2002. Executive summary. In: Wildlife protected networks in India. A review. Wildlife Institute of India, Dehra Dun, India. Pp. 44.
- FSI. (2002). Atlas: Forest Types of India. Forest Survey of India, Dehradun (India)
- Champion, H. G. and Seth, S. K. (1968). A Revised Survey of Forest Types of India, Govt. of India Press, New Delhi, p. 404.
- Singh, J.S. and Gupta, S.R. (1993).Grasslands of Southern Asia. In: Coupland, R.T. (ed.) Natural Grasslands, Eastern Hemisphere and Resume, Ecosystem of the World, 8B, Elsevier.

- Pande, P., Kothari, A and Singh, S. (1991). Directory of National Parks and Sanctuaries in Andaman and Nicobar Islands: Management Status and Profiles, Indian Institute of Public Administration, New Delhi
- Melkania, N.P. and J.S. Singh (1989). Ecology of Indian Grasslands. In: J.S. Singh and B. Gopal (eds.) Prespectives in Ecology, Jagmander Book Agency, New Delhi.
- Singh, J.S., Lauenroth, W.K. and Milchunas, D.G. (1983). Geography of grassland ecosystem. Prog. Geogr. 7:46-80.
- Odum, E.P. (1971). Fundamentals of Ecology.
- Groombridge, B. (1992). Global Biodiversity. Status of the Earth's Living Resources. A Report Compiled by the World Conservation Monitoring Centre, xx + 585 pp. London, Glasgow, New York, Tokyo, Melbourne, Madras: Chapman & Hall.
- Olson et. al., (1983). Major World Ecsosystem Complexes ranked by carbon in live vegetation: a data base. US Department of Energy.
- Singh, P and Bimal Misri (1993). Rangelands resources utilization and management in India. Paper presented at International Symposium on Grassland Resources. Huhehot, Inner Mongolia, P.R.China.
- Rodgers, W.A. and Panwar, H.S. (1988). *Planning a wildlife protected area network in India*. 2 vols. Project FO: IND/82/003. FAO, Dehra Dun. 339, 267 pp.
- Ramakrishna and Venkataraman, K., 2002. Marine Ecosystems. In: Alfred, J.R.B., Das, A.K. and Sanyal, A. K. (ed.), Ecosystems of India, Zoological Survey of India, Kolkata, 1-410.
- CMFRI. (1998-99). Central Marine Fisheries Research Institute. Indian Council of Agricultural Research, Cochin.
- IUCN. (1971). IUCN Yearbook: Annual report of the International Union for Conservation of Nature and Natural Resources for 1970.
- Scott, J. M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Grove, C., Anderson, S, H., Caicco, S., Derchia, F., Edwards, T. C., Jr., Ullman, J., and Wright, R. G. (1993). GAP analysis: A geographic approach to protection of biological diversity. Wildl. Monogr. 123, 1–41.
- Dugan, P.J. (1990): Wetland Conservation: A Review of Current Issues and Required Action, Gland, Switzerland: IUCN, the World Conservation Unit.
- Mudgal V, Hajra P. K. (1999). Floristic Diversity and Conservation Strategies in India: In situ and ex situ conservation. Botanical Survey of India, Ministry of Environment and Forests.
- Singh NP, Karthikeyan S. (2000). Flora of Maharashtra State: Dicotyledones, Vol. I (Ranunculaceae to Rhizophoraceae) Botanical Survey of India.
- Singh, NP, Lakshminarasimhan P, Karthikeyan S, Prasanna PV. (2001). Flora of Maharashtra State: Dicotyledones, Vol. 2: (Combretaceae to Ceratophyllaceae), Botanical Survey of India.
- Jain, S.K. and Sastry, A.R.K. (1983). Materials for a catalogue of threatened plants of India. Botanical Survey of India, Howrah.

- Vavilov, N. I. (1951). The origin, variation, immunity and breeding of cultivated plants. Chronicles Bot. Volume 13. 364 pp.
- Arora, R.K. and E.R. Nayar. (1984). Wild relatives of crop plants in India. NBPGR Sci. Monogr. No. 9. 90 p.
- Nayar, M.P. (1996). Hotspots of Endemic Plants of India, Nepal and Bhutan. TBGRI.
- Sehgal, J.C., D.K. Mondal, C. Mondal and S. Vadi. (1990). Agro-ecological regions of India. NBSS Tech. Bull. No. 24. NBSS & UP, Nagpur. 73 p.
- Nayar, M.P. and Sastry, A.R.K. (1987). Red Data Book of Indian Plants. Vol. 1. Botanical Survey of India, Calcutta. 257
- Nayar, M.P. and Sastry, A.R.K. (1988). Red Data Book of Indian Plants. Vol.2. Botanical Survey of India, Calcutta.
- Nayar, M.P. and Sastry, A.R.K. (1990). Red Data Book of Indian Plants. Vol. 3. Botanical Survey of India, Calcutta.
- Murthy, R.S. and S. Pandey (1978): Delineation of Agro-Ecological Regions of India, Paper presented in Commission V 11th Congress of ISSS, Edmonton, Canada.

10.18 SUGGESTED READING

- Huston, M. A. (1994). Biological Diversity: The Coexistence of Species on Changing Landscapes. Cambridge University Press, New York
- Vold, T. and D.A. Buffett (eds.). 2008. Ecological Concepts, Principles and Applications to Conservation. Available at: www.biodiversitybc.org
- MoE&F & Kalpavriksh. 2004. National Biodiversity Strategy and Action Plan, India: Final Technical Report of the UNDP/GEF Sponsored Project.
- MOE&F. 2009. India's Fourth National Report to the Conventional on Biological Diversity.

10.19 TERMINAL QUESTIONS

1. Define biodiversity. Explain the interrelationship between natural vegetation, wildlife and micro-organisms.

2 What are the main causes of loss of biodiversity? State any four.

3 Describe biodiversity profile at global and national level with suitable examples.

4. Justify the need for conservation of natural vegetation, wildlife and microorganisms with suitable reasons.

5. What are the various threats to the biodiversity? Discuss the causes of loss of biodiversity.

6. India is a mega biodiversity country. Discuss with suitable examples.

UTTARAKHAND OPEN UNIVERSITY

Teenpani Bypass Road, Behind Transport Nagar,
Haldwani- 263139, Nainital (Uttarakhand)
Phone: 05946-261122, 261123; Fax No. 05946-264232
Website: www.uou.ac.in; e-mail: info@uou.ac.in
Toll Free No.: 1800 180 4025