PHYSIO-BIOCHEMISTRY
AND BIOTECHNOLOGY
OF VEGETABLES
Vegetables are defined as fleshy reproductive organ of the plant consisting one or more seeds, which are mainly used for culinary purpose and play a vital role in human nutrition since they constitute an important component of a balanced diet for man by supplying important minerals, vitamins and fibers that are required by the human body for a healthy and active life. In addition, vegetables are also good appetizers and regarded as protective food since they play a vital role in human metabolic process. The added advantage of spice vegetables is their protective nature against several ailments. Most spice vegetables prevent cancer and the attack of harmful bacteria and fungi, while some reduce blood sugar levels, help in digestion and reduce cholesterol levels in the blood serum. Role of vegetables as source of antioxidants in prevention of diseases and delaying aging is also well recognized, and thus, making them important in Indian agricultural economy.

India has made significant progress in the production of vegetables since independence because its diverse agro-climatic zones ranging from tropical to temperate allow the production of a wide spectrum of vegetables. At present, India is the second largest producer of vegetables in the world, after China. Though the country is leading in the production of vegetables, the average consumption per day per capita is very less when compared with other developed countries since the productivity of the vegetables is far less than the advanced countries. The productivity of vegetable crops is seriously influenced by several biotic and abiotic stresses, making the economic conditions of the Indian marginal farmers’ worst.

The plant physiologists in association with plant biotechnologists have to focus their efforts to produce high yielding varieties having resistance against diseases and herbicides and tolerance against drought and salinity and the physical aspects of quality, i.e., shape, size, texture, colour, tenderness, etc. should be given due priority with emphasis to the biochemical and nutritional quality parameters, which include dry matter, proteins, vitamins, sugars, flavouring compounds, alkaloids, flavonoids, etc. However, under present set up of World Trade Organization, the country will have to compete with quality conscious European and developed countries, and with inferior quality product, it would not be possible to penetrate the foreign market. Therefore, breeding programme in a country like India with future-plans of globalization of agriculture produce must be aimed at achieving good nutritional quality. In different types of vegetable, a varied set of biochemical parameters determines the quality.
Under Indian conditions, 25-40% of the total vegetable produce is going waste due to improper harvesting and inadequate post-harvest handling, transportation, storage and processing facilities in the country. However, in some vegetables, the post-harvest losses may be as high as 80-100%. Being highly perishable nature of the vegetables, the losses always increase as the produce moves from harvesting to the consumer. Vegetables with a loss of as little as 5% in fresh weight show shriveled, wilted and staled appearance, which makes the vegetable tissues tough, non-crispy and unpalatable, and eventually, lowers their salability and consumer acceptability considerably. In such situations, the reduction in post-harvest losses of perishables becomes more essential in countries like India.

Vegetables are highly perishable when fresh but can be preserved by a number of processing methods. Owing to the perishable nature of fresh produce, the international trade in vegetables is mostly confined to the processed forms. Fermentation plays an important role in ensuring the food security of millions of people around the world, particularly marginalized and vulnerable groups. This is achieved through improved food preservation, increasing the range of raw materials that can be used to produce edible food products and removing anti-nutritional factors to make the food safe to eat.

This book is aimed at providing systematic information on physiology, post-harvest technology, biochemistry, microbiology and biotechnology of vegetables at a single source. This book containing very concise and precise information on physio-biochemical and biotechnological aspects of vegetable crops has been written in a very simple language, which can be understandable to the postgraduate and doctorate students. It also contains the information on best possible solutions of problems faced by the students, scientists, growers and traders. The information given in this book is truly based on scientific records of scientists working on vegetables in various institutes.

Considering the importance of physiology, post-harvest technology, biochemistry, microbiology and biotechnology of vegetables in view and making the students familiar about these technical aspects of vegetables, the author deemed requisite to prepare a book, which may sequentially help to its users to grasp the knowledge of these basic concepts of vegetable crops. Though a number of books on these individual aspects are available in the library, however, this book on physio-biochemical and biotechnological aspects of vegetable crops compiled for the students of postgraduate and postdoctoral programs is one such attempt to make them learn and understand the subject more precisely and motivate them to improve their knowledge in the field of physio-biochemistry and biotechnology of vegetable crops to meet the future needs. In addition, this book may be user-friendly to others who have the concern to expand basic knowledge in the field of physio-biochemistry and biotechnology of vegetable crops and wish to fetch more remuneration from vegetable crops. Earning scientific knowledge will undoubtedly be rewarding to its users and finally to the nation.

Place: CCS Haryana Agricultural University, Hisar

M.K. Rana
## CONTENTS

*Preface*  
v  
*List of Contributors*  
ix  

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cell Structure and Its Components</td>
<td>Champa Rani, Sunaina Chawla, Vinita Arora and M.K. Rana</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Reproduction</td>
<td>Sunaina Chawla, Vinita arora, Chama Rani and M.K. Rana</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Photosynthesis</td>
<td>Champa Rani, Sunaina Chawla and M.K. Rana</td>
<td>53</td>
</tr>
<tr>
<td>4</td>
<td>Respiration</td>
<td>Sunaina Chawla, Champa Rani and M.K. Rana</td>
<td>87</td>
</tr>
<tr>
<td>5</td>
<td>Photoperiodism: A Physiological and Molecular Concept</td>
<td>A. Hemantaranjan and Anjali Bharti</td>
<td>113</td>
</tr>
<tr>
<td>6</td>
<td>Role of Photoperiodism and Vernalization in Flowering</td>
<td>Saleem Siddiqui and Nidhi</td>
<td>150</td>
</tr>
<tr>
<td>7</td>
<td>Physiology of Fruit Setting and Development</td>
<td>Sunita Sheokand, Chandan Kumar Gupta and Saleem Siddiqui</td>
<td>169</td>
</tr>
<tr>
<td>8</td>
<td>Physiological Disorders of Vegetable Crops</td>
<td>M.K. Rana, Champa Rani and P.K. Sharma</td>
<td>197</td>
</tr>
<tr>
<td>9</td>
<td>Biochemistry and Genetic Manipulation of Fruit Ripening</td>
<td>Sarla Malhotra and Veena Jain</td>
<td>236</td>
</tr>
<tr>
<td>10</td>
<td>Physiology of Dormancy and Seed Germination</td>
<td>Champa Rani, M.K. Rana and Renu Munjal</td>
<td>262</td>
</tr>
<tr>
<td>11</td>
<td>Plant Growth Regulators in Vegetables Production</td>
<td>Champa Rani, Renu Munjal and M.K. Rana</td>
<td>284</td>
</tr>
<tr>
<td>12</td>
<td>Soil-Plant-Water Relationships</td>
<td>R.K. Pannu and Renu Munjal</td>
<td>324</td>
</tr>
<tr>
<td>13</td>
<td>Quantification of Soil and Plant Water Status</td>
<td>K.D. Sharma and Ashok Kumar</td>
<td>348</td>
</tr>
</tbody>
</table>
Chapter 14: Concepts and Management of Drought in Vegetable Crops
M.K. Rana

Chapter 15: Abiotic Stress Tolerance in Vegetable Crops
S. Vincent and H. Vijayaragavan

Chapter 16: Growth and Yield Analysis of Plants
K.D. Sharma and M.K. Rana

Chapter 17: Quality and Factors Affecting Quality of Vegetables
M.K. Rana, Sonia Sood and Ruchi Sood

Chapter 18: Estimation of Quality Parameters in Vegetables
Shashi Madan, M.K. Rana and Renu Munjal

Chapter 19: Management of Post Harvest Losses in Vegetables
M.K. Rana, Sonia Sood and Ruchi Sood

Chapter 20: Preservation of Vegetables through Fermentation
Leela Wati, Kushal Raj and P. Rani

Chapter 21: Plant Tissue Culture: Fundamentals and Applications
Neelam R. Yadav and Ram C. Yadav

Chapter 22: Transgenic Approaches for the Improvement of Vegetable Crops
Neelam R. Yadav, Ram C. Yadav, R.K. Jain and V.K. Chowdhury

Chapter 23: Intellectual Property Rights
Ram C. Yadav and Neelam R. Yadav

Index
LIST OF CONTRIBUTORS

1. **Anjali Bharti**  
   Executive Editor, Advances in Plant Physiology Series  
   Banaras Hindu University  
   Varanasi-221005, Uttar Pradesh, India

2. **A. Hemantaranjan**  
   Department of Plant Physiology  
   Institute of Agricultural Sciences  
   Banaras Hindu University  
   Varanasi 221 005, India

3. **Ashok Kumar**  
   Department of Agronomy  
   CCS Haryana Agricultural University  
   Hisar-125 004, Haryana, India

4. **Champa Rani**  
   Department of Botany and Plant Physiology  
   CCS Haryana Agricultural University,  
   Hisar-125004, Haryana

5. **Chandan Kumar Gupta**  
   Department of Botany and Plant Physiology  
   CCS Haryana Agricultural University  
   Hisar-125004, Haryana, India

6. **H. Vijayaragavan**  
   Department of Crop Physiology  
   Tamil Nadu Agricultural University  
   Coimbatore-641 003  
   Tamil Nadu, India

7. **K.D. Sharma**  
   Department of Agronomy  
   CCS Haryana Agricultural University  
   Hisar-125 004, Haryana, India

8. **Kushal Raj**  
   Department of Plant Pathology  
   CCS Haryana Agricultural University  
   Hisar-125004, Haryana, India

9. **Leela Wati**  
   Department of Microbiology  
   CCS Haryana Agricultural University  
   Hisar-125004, Haryana, India

10. **M.K. Rana**  
    Department of Vegetable Science  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India

11. **Neelam R. Yadav**  
    Department of Biotechnology and Molecular Biology  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India

12. **Nidhi**  
    Department of Botany and Plant Physiology  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India

13. **P.K. Sharma**  
    Department of Plant Physiology  
    CCS Haryana Agricultural University  
    Hisar-125 004, Haryana, India

14. **P. Rani**  
    Department of Microbiology  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India

15. **Ram C. Yadav**  
    Department of Biotechnology and Molecular Biology  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India

16. **Renu Munjal**  
    Department of Plant Physiology  
    CCS Haryana Agricultural University  
    Hisar-125004, Haryana, India
List of Contributors / x

17. **R.K. Jain**  
Department of Biotechnology and Molecular Biology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

18. **R.K. Pannu**  
Department of Agronomy  
CCS Haryana Agricultural University  
Hisar-125 004, Haryana, India

19. **Ruchi Sood**  
Department of Vegetable Science and Floriculture, CSK Himachal Pradesh  
Krishi Vishwavidalaya, Palampur Himachal Pradesh, India

20. **Saleem Siddiqui**  
Centre of Food Science and Technology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

21. **Sarla Malhotra**  
Department of Biochemistry  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

22. **Shashi Madan**  
Department of Biochemistry  
CCS Haryana Agricultural University  
Hisar-125 004, Haryana, India

23. **Sonia Sood**  
Department of Vegetable Science and Floriculture  
CSK Himachal Pradesh  
Krishi Vishwavidalaya, Palampur Himachal Pradesh, India

24. **S. Vincent**  
Department of Crop Physiology  
Tamil Nadu Agricultural University  
Coimbatore-641 003  
Tamil Nadu, India

25. **Sunaina Chawla**  
Department of Botany and Plant Physiology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

26. **Sunita Sheokand**  
Department of Botany and Plant Physiology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

27. **Veena Jain**  
Department of Biochemistry  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

28. **Vinita Arora**  
Department of Botany and Plant Physiology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India

29. **V.K. Chowdhury**  
Department of Biotechnology and Molecular Biology  
CCS Haryana Agricultural University  
Hisar-125004, Haryana, India
Plant body consists of numerous microscopic box like components called cells. The word *cell* has been derived from the Latin word *cellula*, meaning a small room. The descriptive term for this smallest living biological structure was coined by Robert Hooke in a book he published in 1665. When he compared the cork cells, he saw through his microscope to the small rooms monks lived in. The cell is the basic structural and functional unit of all known living organisms. It is the smallest unit of life, which is classified as a living thing and is often called the building block of life (Maton *et al.*, 1997). It is defined as a mass of protoplasm surrounded by a membrane- the plasma membrane- within which complicated chemical reactions are going on.

**History**

- **1632-1723**: Antonie van Leeuwenhoek taught himself to grind lenses, built a microscope and drawn protozoa such as *Vorticella* from rainwater and bacteria from his own mouth.
- **1665**: Robert Hooke discovered cells in cork, then in living plant tissue using an early microscope.
- **1835**: Before the final cell theory was developed, Jan Evangelista Purkinje observed small *granules* while looking at the plant tissue through a microscope.
- **1839**: Theodor Schwann and Matthias Jakob Schleiden elucidated the principle that plants and animals are made of cells and concluded that cells are a common unit of structure and development, and thus, founding the cell theory.
• **1822-1895**: The belief that life forms are able to occur spontaneously (*generatio spontanea*) was contradicted by Louis Pasteur (1822-1895) (although Francesco Redi performed an experiment in 1668 and suggested the same conclusion).

• **1855**: Rudolph Virchow stated that cells always emerge from cell divisions (*omnis cellula ex cellula*).

• **1931**: Ernst Ruska built first transmission electron microscope (TEM) at the University of Berlin. By 1935, he had built an electron microscope (EM) with twice the resolution of a light microscope, revealing previously unresolvable organelles.

• **1953**: Watson and Crick made their first announcement on the double-helix structure for DNA on February 28.

• **1981**: Lynn Margulis published *Symbiosis in Cell Evolution* detailing the endosymbiotic theory.

**Cell Theory (Cell Doctrine)**

In 1939, two scientists M.J. Schleiden and Theodor Schwann formulated a theory that “all the living organisms are composed of one or more cells, which come from pre-existing cells, that vital functions of an organism occur within cells and that all cells contain the hereditary information necessary for regulating cell functions and for transmitting information to the next generation of cells”. The present day concept of cell is resultant of findings made by several investigators from time to time by applying better techniques. Electron microscopy reveals a better understanding of cell components. Microscopes make it possible to magnify small objects such as cells in order to see the details of their structure. Both, light and electron microscopes are used to study cells. The study of cells with a microscope is called cytology. One-celled organisms are called unicellular organisms and those with more than one cell are called multi-cellular organisms. Virus particles do not have any cells, and are therefore, termed as acellular.

**Size and Shape of the Cells**

Cells vary in size and shape. The units of measurement are micron and angstrom (Å). One micron (µ) is equal to 1/1000 mm and 1 angstrom (Å) is equal to 0.001 micron. The smallest cell known so far measures about 0.1 to 2.5 micron in diameter in mycoplasma, whereas, the longest cell reported to reach 55 cm in length among the bast fibres of *Boehmeria nivea* (Albada, 1927). The shape of the cells may be rounded, oval, elliptical, spindle shaped, block-shaped, polygonal, columnar, discoidal, flat, or plate like. The typical size of the cell mostly depends on its genetic factors or on other internal or external factors such as hormones, mechanical pressure and surface tension.
Structure of the Cell

Internal organization of plant cells reveals that it has an outer boundary of cell wall lined by a cell membrane. Within the cell membrane, a fluidic substance called cytoplasm is filled in which a variety of organelles, vesicles, inclusions and granules are suspended. Cytoplasm consists of free amino acids, proteins, glucose and numerous other molecules. The cell environment (i.e., the contents of the cytoplasm and the nucleus as well as the way the DNA is packed) affects the gene expression/ regulations, and is thus, very important part of inheritance. Usually, the nucleus bounded by double membranous nuclear envelope is present in almost all living cells. Thus, depending upon the presence or absence of nuclear envelop, the living organisms are divided into two basic categories, i.e., (i) prokaryotes that lack an organized nucleus and (ii) eukaryotes that possess a definite nucleus.

Prokaryotic cells are usually independent, while eukaryotic cells are often found in multicellular organisms. Cells are also classified according to their need for energy. Autotrophs are self-feeders that use light or chemical energy to make food. Plants are an example of autotrophs. In contrast, heterotrophs (other feeders) obtain energy from other autotrophs or heterotrophs. Many bacteria and animals are heterotrophs.

Prokaryotic cells

Prokaryotes include bacteria and blue-green algae (cyanobacteria). Simply stated, prokaryotes are molecules surrounded by a membrane and cell wall. The prokaryote cell is simpler and smaller than a eukaryote cell. Prokaryotic cells lack characteristic eukaryotic subcellular membrane-enclosed organelles but may contain membrane systems inside a cell wall as an extension or infoldings of the cell membrane. The nucleus is not well organized and is without any membrane (Figure 1.1).

A prokaryotic cell has three architectural regions:

- On the outside, flagella and pili arise from the cell’s surface. These are structures (not present in all prokaryotes) made of proteins that facilitate movement and communication between cells.
• Enclosing the cell is the cell envelope, generally, consisting of a cell wall covering a plasma membrane though some bacteria also have a further covering layer called a capsule. The envelope gives rigidity to the cell and separates the interior of the cell from its environment, serving as a protective filter. Though most prokaryotes have a cell wall, there are exceptions such as Mycoplasma (bacteria) and Thermoplasma (archaea). The cell wall consists of peptidoglycan in bacteria and acts as an additional barrier against exterior forces. It also prevents the cell from expanding and finally bursting (cytolysis) from osmotic pressure against a hypotonic environment. Some eukaryote cells (plant and fungi cells) also have a cell wall.

• Inside the cell is the cytoplasmic region that contains the cell genome (DNA) and ribosomes and various sorts of inclusions. A prokaryotic chromosome is usually a circular molecule (an exception is that of the bacterium Borrelia burgdorferi, which causes Lyme disease). Though not forming a nucleus, the DNA is condensed in a nucleoid. Prokaryotes can carry extrachromosomal DNA elements called plasmids, which are usually circular. Plasmids enable additional functions, such as antibiotic resistance.

Prokaryotic cells may have photosynthetic pigments, such as is found in cyanobacteria (blue-green algae). Prokaryotic cells come in multiple shapes, i.e., round (Cocci), rods (Baccilli) and helical (Spirilla or Spirochetes) cells. All prokaryotes are unicellular organisms and eukaryotes include both unicellular and multicellular organisms.

**Eukaryotic cells**

Eukaryotic cells are about 15 times the size of a typical prokaryote and can be as much as 1000 times greater in volume (figure 2). A typical eukaryotic cell consists of mainly two parts, i.e., (i) cell wall and (ii) protoplast. The protoplast is further divided into protoplasm and ergastic substances.

![Diagram of a plant cell, showing sub-cellular components](image)
The major difference between prokaryotes and eukaryotes is that the eukaryotic cells contain membrane-bound compartments in which specific metabolic activities take place (figure 2). Most important among these is the presence of a cell nucleus, a membrane-delineated compartment that houses the eukaryotic cell’s DNA. It is this nucleus, which gives the eukaryote its name, meaning *true nucleus*. Other differences include:

- The plasma membrane resembles that of prokaryotes in function, with minor differences in the setup. Cell walls may or may not be present.
- The eukaryotic DNA is organized in one or more linear molecules, called chromosomes, which are associated with histone proteins. All chromosomal DNA is stored in the *cell nucleus*, separated from the cytoplasm by a membrane. Some eukaryotic organelles such as mitochondria also contain some DNA.
- Many eukaryotic cells are ciliated with *primary cilia*. Primary cilia plays an important role in chemosensation, mechanosensation and thermosensation, thus, cilia may be “viewed as sensory cellular antennae that coordinate a large number of cellular signaling pathways, sometimes, coupling the signaling to ciliary motility or alternatively to cell division and differentiation”.
- Eukaryotes can move using *motile cilia* or *flagella*. The flagella are more complex than the prokaryotes.
## Table 1.1. Comparison of prokaryotic and eukaryotic cells features

<table>
<thead>
<tr>
<th>Components</th>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical organisms</strong></td>
<td>Bacteria and archaea</td>
<td>Protists, fungi, plants and animals</td>
</tr>
<tr>
<td><strong>Typical size</strong></td>
<td>–1-10 micro m</td>
<td>–10-100 micro-m (sperm cells, apart from the tail, are smaller)</td>
</tr>
<tr>
<td><strong>Type of nucleus</strong></td>
<td>Nucleoid region and no real nucleus</td>
<td>Real nucleus with double membrane</td>
</tr>
<tr>
<td><strong>DNA</strong></td>
<td>Circular (usually)</td>
<td>Linear molecules (chromosomes) with histone proteins</td>
</tr>
<tr>
<td><strong>RNA-/protein-synthesis</strong></td>
<td>Coupled in cytoplasm</td>
<td>RNA-synthesis inside the nucleus protein synthesis in cytoplasm</td>
</tr>
<tr>
<td><strong>Ribosomes</strong></td>
<td>50S + 30S</td>
<td>60S + 40S</td>
</tr>
<tr>
<td><strong>Cytoplasmatic structure</strong></td>
<td>Very few structures</td>
<td>Highly structured by endomembranes and a cytoskeleton</td>
</tr>
<tr>
<td><strong>Cell movement</strong></td>
<td>Flagella made of flagellin</td>
<td>Flagella and cilia containing microtubules; lamellipodia and filopodia containing actin</td>
</tr>
<tr>
<td><strong>Mitochondria</strong></td>
<td>None</td>
<td>One to several thousand (though some lack mitochondria)</td>
</tr>
<tr>
<td><strong>Chloroplasts</strong></td>
<td>None</td>
<td>In algae and plants</td>
</tr>
<tr>
<td><strong>Organization</strong></td>
<td>Usually single cells</td>
<td>Single cells, colonies, higher multicellular organisms with specialized cells</td>
</tr>
<tr>
<td><strong>Cell division</strong></td>
<td>Binary fission (simple division)</td>
<td>Mitosis (fission or budding) and meiosis</td>
</tr>
</tbody>
</table>

All cells, whether prokaryotic or eukaryotic, have a membrane that envelopes the cell, separates its interior from its environment, regulates what moves in and out (selectively permeable) and maintains electric potential of the cell. Inside the membrane, a salty cytoplasm takes up most of the cell volume. All cells possess DNA, the hereditary material of genes and RNA containing information necessary to build various proteins such as enzymes, the cell’s primary machinery. There are also other kinds of biomolecules in cells:

### Cell Wall

A cell wall is a tough, usually flexible, but sometimes, fairly rigid layer that surrounds plant cells. It is located outside the cell membrane and provides these cells with structural support and protection and also acts as a filtering mechanism. A major function of the cell wall is to act as a pressure vessel, preventing over-expansion when water enters the cell. They are found in plants, bacteria, fungi, algae and some archaea. Animals and protozoa do not have cell walls.

- **Plant cell wall** has three layers:
  - **Middle lamella**: It is a layer rich in pectins. This outermost layer forming the interface between adjacent plant cells and glues them together.
  - **Primary cell wall**: It is generally a thin, flexible and extensible layer formed, while the cell is growing.
• **Secondary cell wall**: It is a thick layer formed inside the primary cell wall after the cell is fully-grown. It is not found in all types of cell. In some cells generally found in xylem, the secondary wall contains lignin, which strengthens the wall and makes it water proof.

**Formation of Plant Cell Walls**

**Middle lamella**

First of all, the middle lamella formed from cell plate during cytokinesis is laid down and the primary cell wall is then deposited inside the middle lamella. The actual structure of the cell wall is not clearly defined and several models exist, i.e., the covalently linked cross model, the tether model, the diffuse layer model and the stratified layer model. However, the primary cell wall can be defined as composed of cellulose microfibrils aligned at all angles. Microfibrils are held together by hydrogen bonds to provide a high tensile strength. The cells are held together and share the gelatinous membrane called the *middle lamella*, which contains magnesium and calcium pectates (salts of pectic acid). Cells interact through plasmodesmata, which are inter-connecting channels of cytoplasm that connect to the protoplasts of adjacent cells across the cell wall (Figure 1.3).

In some plants and cell types, after a maximum size or point in development has been reached, a *secondary wall* is constructed between the plant cell and primary wall. Unlike primary wall, the microfibrils are aligned mostly in the same direction, and with each additional layer, the orientation changes slightly. Cells with secondary cell walls are rigid. Cell to cell communication is possible through *pits* in the secondary cell wall that allow plasmodesmata to connect cells through the secondary cell walls.

**Primary cell wall**

It is made up of the major carbohydrates such as cellulose, hemicellulose and pectin (Figure 1.3). The cellulose microfibrils are linked via hemicellulosic tethers to form a cellulose-hemicellulose network, which is embedded in the pectin matrix. The most common hemicellulose in the primary cell wall is xyloglucan. In grass cell walls, xyloglucan and pectin are reduced in abundance and partially replaced by glucuronarabinoxylan, a hemicellulose. Primary cell walls characteristically extend (grow) by a mechanism called acid growth, which involves turgor-driven movement of the strong cellulose microfibrils within the weaker hemicellulose/pectin matrix, catalyzed by expansin proteins. The outer part of the primary cell wall of the plant epidermis is usually impregnated with cutin and wax, forming a permeability barrier known as the plant cuticle (Albersheim, 1976; Capita and Gibeaut, 1993).

**Secondary cell wall**

It contains a wide range of additional compounds that modify their mechanical properties and permeability (figure 3). The major polymers that make up wood (largely secondary cell walls) include cellulose (35-50%), xylem, a type of hemicellulose (20-35%) and a complex phenolic polymer called lignin (10-25%). Lignin penetrates the spaces in the
cell wall between cellulose, hemicellulose and pectin components, driving out water and strengthening the wall. The walls of cork cells in the bark of trees are impregnated with suberin, and suberin also forms the permeability barrier in primary roots known as the casparian strip. Secondary walls, especially in grasses, may also contain microscopic silica crystals, which may strengthen the wall and protect it from herbivores.

Plant cells walls also contain numerous enzymes, such as hydrolases, esterases, peroxidases, and transglycosylases that cut, trim and crosslink wall polymers. Small amounts (1-5%) of structural proteins are found in most of the plant cell walls, which are classified as hydroxyproline-rich glycoproteins (HRGP), arabinogalactan proteins (AGP), glycine-rich proteins (GRPs) and proline-rich proteins (PRPs). Each class of glycoprotein is defined by a characteristic, highly repetitive protein sequence. Most of the glycoproteins are glycosylated, contain hydroxyproline (Hyp) and become cross-linked in the cell wall. These proteins are often concentrated in specialized cells and in cell corners. Cell walls of the epidermis and endodermis may also contain suberin or cutin, two polyester-like polymers that protect the cell from herbivores. The relative composition of carbohydrates, secondary compounds and protein varies between plants and between the cell type and age.

**Functions of Cell Wall**

- The primary cell wall of most plant cells is semi-permeable and permits the passage of small molecules and small proteins, with size exclusion estimated to be 30-60 kDa. The key nutrients, especially water and carbon dioxide, are distributed throughout the plant from cell wall to cell wall in apoplastic flow.

- Cell walls in some plant tissues also function as storage depots for carbohydrates that can be broken down and resorbed to supply the metabolic and growth needs of the plant, e.g., endosperm cell walls in the seeds of cereal grasses, nasturtium, and other species are rich in glucans and other polysaccharides that are readily digested by enzymes during seed germination to form simple sugars that nourish the growing embryo. However, cellulose microfibrils are not readily digested by plants (Selvendran and O’Neill, 1985).

- The wall gives cells rigidity and strength, offering protection against mechanical stress. In multicellular organisms, it permits the organism to build and hold its shape.

- The cell wall also limits the entry of large molecules, which may be toxic to the cell. It further permits the creation of a stable osmotic environment by preventing osmotic lysis and helping to retain water. The composition, properties, and form of the cell wall may change during the cell cycle and depend on growth conditions.

In plants, secondary cell wall is a thicker additional layer of cellulose, which increases wall rigidity. Additional layers may be formed containing lignin in xylem cell walls, or containing suberin in cork cell walls. These compounds are rigid and waterproof, making the secondary wall stiff. Both wood and bark cells of trees have secondary walls (Cosgrove, 2001).
Figure 1.3. (A) Molecular structure of the primary cell wall in plants. (B) and (C) Schematic representation of primary and secondary cell walls and their relationship to rest of the cell.
Protoplast

The actively metabolizing part that consists of living and non-living components is commonly termed as protoplast. It includes plasma membrane and all that it encloses. Protoplast consists of four parts, i.e., (i) cytoplasm, (ii) nucleus, (iii) vacuoles and (iv) ergastic substances. Cytoplasm and nucleus are collectively known as protoplasm (Bhatla et al., 2002).

Protoplasm is defined as the substance within and including plasma membrane of a cell usually excluding large vacuoles and masses of secretion. Protoplast is considered as the physical basis of life because most of the metabolic biological and physiological activities of life occur in it. Under high magnification, the protoplasm appears as a viscous, colourless, transparent material with various inclusions. Protoplasm consists of oxygen 62%, carbon 20%, hydrogen 10% and nitrogen 3%. Remaining 5% part consists of about 30 elements of which calcium, iron, magnesium, chlorine, phosphorus, potassium, sulfur, etc. are important. The protoplasm particles that are bounded by membrane are termed as organelles (Davey et al., 2005). The various components of protoplasm are given as under:

Cytoplasm

The cytoplasm matrix, i.e., cytosol, is most important part of cell. The name cytoplasm was given by Kolliker (1962) to the substance found around the nucleus. Portion of protoplasm, that extends from cell membrane to nuclear membrane excluding vacuoles is termed as cytoplasm. It is a complete watery fluid, which contains many molecular substances. Some substances remain in the form of colloidal suspension. It exhibit hydrostatic pressure action, several mechanical properties, changes in viscosity and carries out many bio-synthetic functions of the cell. The pH of the protoplasm is about 6.8. Water is the most abundant component of cytoplasm. It contains several enzymes, proteins and several other substances viz., carbohydrates, lipids, nucleic acids, etc. The cytoplasm includes several sub-microscopic inclusions known as cell organelles. The various components (cell organelles) of cytoplasm are:

- Plasma membrane
- Vacuolar membrane (tonoplast)
- Endoplasmic reticulum
- Mitochondria
- Plastids
- Ribosomes
- Golgi apparatus
- Microbodies
- Microtubules

Plasma membrane

It is also known as cell membrane. It is the defining boundary of a cell, which surrounds the cytoplasm of a cell. The plasma membrane in plants and prokaryotes is usually covered by a cell wall. This membrane serves to separate and protect a cell from its
surrounding environment, and it is made mostly from a double layer of lipids (hydrophobic fat-like molecules) and hydrophilic phosphorus molecules. Hence, the layer is called a phospholipid bilayer. It may also be called a fluid mosaic membrane (figure 4). Embedded within this membrane is a variety of protein molecules that act as channels and pumps, which facilitate the movement of different molecules into and out of the cell. The membrane is said to be semi-permeable, in which a substance (molecule or ion) passes through freely, passes through to a limited extent, or not passes through at all. Cell membranes on their surface also contain receptor proteins that allow the cells to detect external signaling molecules such as hormones (Singer and Nicholson, 1972).

![Diagram of a plasma membrane showing proteins embedded in phospholipid bilayer](image)

**Figure 1.4.** Plasma membrane of plant cells showing proteins embedded in phospholipid bilayer

Electron microscopic studies revealed that plasma membrane is three layered. The two outer layers are dense and approximately 20 A° thick and the middle layer is about 35 A° thick. This three-layered structure is called the unit membrane.

Various models have been proposed to explain the structure and composition of plasma membrane. Davson and Danielli (1935, 1952) proposed the trilaminar *sandwich model* to describe the structure of a unit membrane. According to them, a bimolecular layer of lipid is sand-witched between two protein layers. These layers are held together hydrostatically. Electron microscopy reveals that fatty acids (lipophillic) tails of lipids face with each other along the double row. The hydrophilic heads of lipids face towards positively charged protein layer.

Higher resolution electron microscopic studies reveal that proteins appear to be distributed throughout the membrane rather than restricted to a coating on each side of phospholipid bimolecular layer. Based on these studies, Singer and Nicholson (1972, 1974) proposed the *fluid mosaic model*, which states that membranes are made up of an oriented sheet of phospholipids which are amphipathic in nature (asymmetric distribution of charges in the polar groups). The non-polar groups face each other and interact hydrophobically. There are two types of proteins, *i.e.*, (i) peripheral proteins and (ii) Integral proteins, associated with phospholipid layer.
The peripheral proteins can easily be separated from the membrane by mild treatment, i.e., changes in ionic strength of the buffer. The integral proteins can be separated by drastic treatments, viz. by organic solvents.

The lipid bilayer forms a fluid matrix, which acts as a permeability barrier and may have some active role in ion ATPase activity. The globular proteins are either embedded (integral or intrinsic) or are attached at the surface (peripheral or extrinsic), which gives a mosaic appearance to the membrane. The integral proteins are globular and embedded in the bilayer of lipid. These proteins might emerge at one face of the bilayer or at both. The peripheral proteins, on the other hand, are bound to surface of membrane largely by electrostatic interactions. The lipids are free to move about laterally and the proteins are capable of moving about in the lipid bilayer. The proteins are mainly concerned with enzymatic activity and transport of molecules across the membrane.

Vacular membrane
Each vacuole of plant cell is surrounded by single lipoproteinic membrane, called tonoplast. It is similar in structure and function to plasma membrane. It is selectively or differentially permeable and responsible for important biochemical activities of plant cell. Different transport processes occurring at vacular membrane have been discussed by Martinoia et al. (2000). There are different types of vacular membrane protein, the aquaporins. Two vacular protein pumps, i.e., (i) an ATPase and (ii) PPase(pyro-phosphatase), energize the vacular uptake of most solutes. Plant secondary products can be accumulated by proton antoprot mechanism.

Endoplasmic reticulum (ER)
Semiviscous fluid of cytoplasm is traversed by membrane bound vesicular system called endoplasmic reticulum (Figure 1.5). The membranes of endoplasmic reticulum are typical lipid bilayers with interspersed integral and peripheral proteins. These membranes form
flattened or tubular sacs known as *cisternae*. It is the transport network for molecules targeted for certain modifications and specific destinations as compared to molecules, which will float freely in the cytoplasm. The network of endoplasmic reticulum separates cytoplasm of the cell into several small compartments. This compartmentalization of the cytoplasm helps a cell to perform specific activities by providing enzymes and metabolites within specific chambers excluding others (Faye et al., 1992). Walter et al. (1984) studied protein translocation across endoplasmic reticulum.

The endoplasmic reticulum has two forms given below:

- **Rough (granular) ER**: It is the endoplasmic reticulum, which has ribosomes on its surface and secretes proteins into the cytoplasm.

- **Smooth (agranular) ER**: It is the endoplasmic reticulum, which lacks ribosomes. Smooth ER plays a role in calcium sequestration and release. It functions as the main site of lipid synthesis and membrane assembly.

### Functions of Endoplasmic Reticulum

- The ER gives mechanical support to the cytoplasm.
- It has osmotic properties, and therefore, it is involved in intracellular exchange of materials.
- ER serves as circulatory system for the transportation of cellular molecules and helps in the storage of synthesized molecules.
- It is usually concerned with the synthesis of lipids, lipo-proteins and cell wall materials in differentiating cells. It plays important role in the synthesis of new nuclear membrane during cell division.
- It is involved in metabolism of cholesterol and steroid hormones.
- It causes detoxification of many endogenous and exogenous compounds.

### Mitochondria

Mitochondria are self-replicating, semiautonomous organelles that occur in various numbers, shapes, and sizes in cytoplasm of all the eukaryotic cells (Figure 1.6). Mitochondria play a critical role in generating energy in the eukaryotic cell. Mitochondria generate cell’s energy by the process of oxidative phosphorylation, utilizing oxygen to release energy stored in cellular nutrients (typically pertaining to glucose) to generate ATP. Because of this, the mitochondria are called powerhouse of the cell. Mackenzie (1999) studied the structure of higher plants mitochondria, which multiply by splitting in two. Size of the mitochondria varies from 0.2 to 1.0 micron in diameter and 2 to 8 micron long. They contain mitochondrial DNA, RNA and ribosomes to carry on protein synthesis. Therefore, these cellular organelles are capable of growth and replication, independent of the parent cells. Translocation of proteins into mitochondria is studied by Schatz and Butow (1983). Mitochondria carry out oxidation of dicarboxylic or tri-carboxylic acids resulting into their oxidation products (CO\(_2\), H\(_2\)O and ATP). In cucumber fruits, respiration is accompanied by physiological injury at chilling temperature (Eaks and Morris, 1956). Ku et al. (1968) isolated active mitochondria from tomato fruit. Mitochondrion is an integration point of cellular metabolism and signaling. It retains an important role in
numerous metabolic processes such as catabolism of amino acids, provision of carbon skeletons for biosynthesis of a wide range of compounds including amino acids, vitamins, lipids and tetrapyrroles (Sweetlove, 2007).

Mitochondria and chloroplasts each contain their own genome, which is separate and distinct from the nuclear genome of a cell. Both of these organelles contain DNA in circular plasmids, much like prokaryotic cells, strongly supporting the evolutionary theory of endosymbiosis. Since these organelles contain their own genomes and have other similarities to prokaryotes, they are thought to have developed through a symbiotic relationship after being engulfed by a primitive cell (Slonimski et al., 1982; Steinback et al., 1985; Foyer and Noctor, 2003).

Plastids of higher plants exist in a variety of forms and these plastids have a wide range of structure and function. All plastids are bounded by a double-layered covering membrane. One type of plastid can change into other type. They are involved in the energy-metabolism storage activity and reproduction of plants. Plastids are of different types described as under:

**Chloroplasts:** These are chlorophyll (green pigment) containing plastids. Usually, they are found in the mesophyll and palisade cells of angiosperms, gymnosperms, pteridophytes and vegetative green cells of lower plants. They are usually discoid, ellipsoidal or biconvex lens shaped. Chloroplasts of higher plants are 4-10 µ in diameter and 1-3 µ in thickness (Figure 1.7). An average fresh chloroplast contains water about 50%, proteins 25%, lipids 15% and pigments 10%. The chemical composition of chloroplast excluding water shows proteins 50-60%, phospholipids 21-34%, chlorophyll ‘a’ and chlorophyll ‘b’, 5-8% carotenoids 0.7%, RNA 1.75% and DNA 0.02-1%. They are specialized to harvest light energy and utilize it in the fixation of carbon and manufacture the light energy molecules involved in cellular energy metabolism. They are involved in energy storage through the process of photosynthesis, which utilizes solar energy to generate carbohydrates and oxygen from carbon dioxide and water. A typical parenchymatous cell contains 10-100 chloroplasts. They are semi-autonomous. Chloroplast has its own DNA, which codes for redox proteins involved in electron transport in photosynthesis, and this is termed as plastome.
Recently, chloroplasts have caught attention by developers of genetically modified plants. In most flowering plants, chloroplasts are not inherited from the male parent (Stegemann et al., 2003; Ruf et al., 2007), although in plants such as pines, the chloroplasts are inherited from male (Powell et al., 1995). Where chloroplasts are inherited only from the female, transgenes in these plastids cannot be disseminated by pollen. This makes the plastid transformation a valuable tool for the creation and cultivation of genetically modified plants that are biologically contained, thus, posing significantly lower environmental risks. This biological containment strategy is therefore suitable for establishing the coexistence of conventional and organic agriculture. While the reliability of this mechanism has not yet been studied for all relevant crop species, recent results in tobacco plants are promising, showing a failed containment rate of transplastomic plants at 3 in 1,000,000 (Ruf et al., 2007).

**Proplastids (eoplasts):** These are small colourless or pale green spherical structures bounded by double-layered membrane. These undifferentiated plastids occur in meristematic cells of the shoot and root. They are capable of giving rise to various types of plastid. Under normal conditions, i.e., in the presence of light, they are transformed to chloroplasts. If they do not get light and the plant organ grows in dark, they are changed to etioplasts.

**Etioplasts:** These are the plastids formed in the cells of cotyledons and leaves grown in dark. They are transformed from proplastids. The etioplasts are characterized by having one or more crystalline prolamellar bodies. These plastids also contain carotenoids and protochlorophyllide. On getting light, the etioplasts can convert into chloroplasts.

**Amyloplasts:** These are the plastids in which most of their internal volume is filled with starch. The amyloplasts are the sites where starch is synthesized and stored as a reserve food material in non-green tissues such as cotyledons, endosperms and tubers.

**Elaioplasts:** These plastids synthesize and store fat. They are found in epidermal cells of some monocot families.
**Proteinoplasts or aleuronoplasts:** These are plastids, which contain protein. These are found in plastids of meristematic cells as well as in mature epidermal and guard cells.

**Chromoplasts:** These are carotenoid containing plastids responsible for yellow, orange and red colours of fruits, floral parts and some roots, e.g., tomato, carrot, etc. They can attain various shapes. Electron micrograph of a chromoplast from tomato fruit at an early stage shows the transition from chloroplast to chromoplast (Gunning and Steer, 1996).

**Gerontoplasts:** These are senescent chloroplasts usually found in ageing leaves.

After harvesting, certain factors, such as storage and cooking, influence the texture of fruits and vegetables in terms of chemical and physical changes, which occur (Ainsworth, 1994).

**Ribosome (Microsome)**

The ribosome is a large complex of RNA and protein molecules. Each ribosome consists of two subunits and act as an assembly line where RNA from the nucleus is used to synthesize proteins from amino acids. Ribosomes can be found either floating freely or bound to a membrane (the rough endoplasmatic reticulum in eukaryotes, or the cell membrane in prokaryotes). They are found in the nucleus, chloroplast and mitochondria. The ribosomes are 150 to 230 Å in diameter and have sedimentation coefficient of 70S in prokaryotic cells and 80S in eukaryotic cells of higher plants. Each ribosome is made up of two sub-units. The ribosomes of prokaryotic cells are made up of 50S and 30S sub-units, whereas, of eukaryotic cells are made up of 60S and 40S sub-units. The association or disassociation of ribosomal sub-units depends on magnesium (Mg$^{++}$) ion concentration. The outer boundary of ribosome is an envelope of protein, which surrounds ribosomal RNA. The ribosomes consist of 60% rRNA and 40% basic proteins. Electron microscopy reveals that ribosomes are often found in clusters to which RNA is attached, is called polyribosomes or polysomes. The function of ribosomes is to provide template for the synthesis of proteins.

**Golgi apparatus or Dictyosome**

Dictyosomes are universally present in all plant cells and measures about 2 µm in diameter and about 0.5 micrometer in width (figure 8). The central portion of dictyosome consists of a series of stacked discs, each composed of flattened sac like saccule or cisternae bounded by two bodies, or vesicles, which appear to be released from dilated margins of discs. These vesicles are of two types, i.e., (i) smooth walled and (ii) sculptured. The primary function of Golgi apparatus is to process and package the macromolecules such as proteins and lipids that are synthesized by the cell. It is particularly important in the processing of proteins for secretion. The Golgi apparatus forms a part of endomembrane system of eukaryotic cells (Wee et al., 1998). Vesicles that enter the Golgi apparatus are processed in a cis to Trans-direction, meaning they coalesce on the cis side of the apparatus and after processing pinch off on the opposite (Trans) side to form a new vesicle. They are also involved in the cell plate formation (Driovich et al., 1994; Juniper et al., 1982). The membrane protein transport between the endoplasmic reticulum and the Golgi in tobacco leaves is energy dependent but cytoskeleton independent (Brandizzi et al., 2002).
Microbodies

A large number of tiny membrane bound bags called microbodies are universally present in all plant cells. These are described as below:

*Spherosomes*: The spherosomes are similar to lysosomes of animal cells. These are spherical vesicles originating from the ends of endoplasmic reticulum. The outermost boundary of these organelles is single membrane made up of lipoprotein. They measure approximately 0.5 to 1.0 micrometer in diameter. The spherosomes contain hydrolytic enzymes, which are released by the rupturing of membrane, when needed. These bodies are sometimes termed as suicide bags, because they not only hydrolyse the external particles but also destroy the nearby cytoplasm and finish themselves (Harwood, 1997; Murphy, 1990).

*Peroxisomes*: These are membrane bound microbodies found in the cells of green leaves. They measure 0.5 micrometer in diameter. Peroxisomes have enzymes that rid the cell of toxic peroxides. The peroxisomes contain catalase, together with the enzymes of glycolate pathway, i.e., glycolate oxidase, glyoxylate reductase, glutamate-glyoxylate transminase, etc.

*Glyoxysomes*: These are the membrane bound spherical particles (0.5-1.0 micrometer diameter), which were first isolated from castor bean endosperm. They are usually present in germinating fatty seeds where fat is being converted to carbohydrates. The glyoxysomes contain enzymes of glyoxylate cycle.

*Lomasomes*: These are vesicular and membranous structure usually present between the cell wall and the plasma membrane of plant cells. They appear to be originated from Golgi bodies. Their definite function is not known, but probably, they help in cell wall elaboration.

Microtubules

These are elongated, cylindrical, unbranched, non-membranous, hollow tube like structure present in all the actively dividing and elongating cells. They constitute major portion in flagella and cilia of motile cells. They are present mainly in ectoplasm or in cytoplasm.
below the plasma membranes in most of the cells. They have a diameter of 25 nm and length varying from 200 nanometers to 25 micrometers. Microtubules serve as structural components within cells and are involved in many cellular processes including mitosis, cytokinesis and vesicular transport (Vale et al., 1985).

Microtubules are polymers of alpha- and beta-tubulin dimers. The tubulin dimers polymerize end to end in protofilaments. The protofilaments then bundle into hollow cylindrical filaments. Typically, the protofilaments arrange themselves in an imperfect helix with one turn of the helix containing 13 tubulin dimers each from a different protofilament. Microtubules are nucleated and organized by the microtubule organizing centers (MTOCs), such as centrioles and basal bodies. Microtubules are part of a structural network (the cytoskeleton) within cytoplasm of the cell, but in addition to structural support, microtubules take part in many other processes as well. They are capable of growing and shrinking in order to generate force, and there are also motor proteins that allow the organelles and other cellular factors to move along the microtubule (Barisy et al., 1984)

Main functions of microtubules are:

- Formation of spindle fibers during mitosis and help in separation of homologous chromosomes during telophase,
- Formation of cell wall by directing the alignment of cellulose microfibrils,
- Formation of cytoskeleton and
- Constitution of a major portion in flagella and cilia.

**Vacuole**

Vacuole is a membrane organelle, which is present in all plant and fungal cells and some protist, animal and bacterial cells. Vacuoles are essentially enclosed compartments, which are filled with water containing inorganic, and organic molecules including various enzymes in solution, though in certain cases, they may contain solids, which have been engulfed (Figure 1.2). Vacuoles contain dissolved salts such as organic acids, soluble carbohydrates, soluble nitrogenous compounds, enzymes, tannins, anthocyanin pigments, alkaloids, inorganic salts, etc. Vacuoles are formed by the fusion of multiple membrane vesicles and are effectively just larger forms of these. Although this organelle has no basic shape or size but its structure varies according to needs of the cell.

Vacuoles also play a major role in autophagy, maintaining a balance between biogenesis (production) and degradation (turnover), of many substances and cell structures in certain organisms. They also aid in destruction of invading bacteria or of misfolded proteins that have begun to build up within the cell. Most mature plant cells have one large central vacuole that typically occupies more than 30% of the cell’s volume and that can occupy as much as 80% of the volume for certain cells and conditions. Strands of cytoplasm often run through the vacuole.

A vacuole is surrounded by a membrane called tonoplast, which is also called the vacuolar membrane. The tonoplast separates the vacuolar contents from cytoplasm of the cell. As a membrane, it is mainly involved in regulating the movements of ions around the cell and isolating materials that might be harmful or a threat to the cell.
Transport of protons from the cytosol to the vacuole stabilizes cytoplasmic pH while making the vacuolar interior more acidic creating a proton motive force to which the cell can use to transport nutrients into or out of the vacuole. The low pH of the vacuole also allows degradative enzymes to act. Though single large central vacuoles are most common, the size and number of vacuoles may vary in different tissues and stages of development, e.g., the developing cells in the meristems contain small provacuoles, and cells of the vascular cambium have many small vacuoles in winter and one large one in summer.

Aside from storage, the main role of central vacuole is to maintain turgor pressure against cell wall. Proteins found in the tonoplast (aquaporins) control the flow of water into and out of the vacuole through active transport, pumping potassium (K⁺) ions into and out of the vacuolar interior. Due to osmosis, water will diffuse into the vacuole, placing pressure on the cell wall. If water loss leads to a significant decline in turgor pressure, the cells will plasmolyse. Turgor pressure exerted by vacuoles is required for cellular elongation, as the cell wall is partially degraded by the action of expansins. The less rigid wall is expanded by the pressure coming from within the vacuole. Turgor pressure exerted by the vacuole is also essential in supporting plants in an upright position. Another function of a central vacuole is that it pushes all contents of the cell’s cytoplasm against cellular membrane, and thus, keeps the chloroplasts closer to light. Some plants store chemicals in the vacuole, which react with chemicals in the cytosol. If the cell is broken, for example by an herbivore, the two chemicals can then react forming toxic chemicals. In garlic, alliin and the enzyme alliinase are normally separated but form allicin if the vacuole is broken. A similar reaction is responsible for the production of syn-propanethial-S-oxide when onions are cut.

**Functions of Vacuole**

- Isolates the materials that might be harmful or a threat to the cell.
- Contains waste products.
- Maintains internal hydrostatic pressure or turgor within the cell.
- Maintains an acidic internal pH.
- Contains small molecules.
- Exports unwanted substances from the cell.
- Allows the plants to support structures such as leaves and flowers due to the pressure of the central vacuole.

**Nucleus**

Sometimes, the nucleus is also referred to as the *control center* of the cell. It is a membrane-enclosed organelle found in eukaryotic cells. The average diameter of the nucleus is approximately 6 micrometer, which occupies about 10% of the total cell volume (Figure 1.9). It appears as a dense, roughly spherical organelle. It contains most of the cell’s genetic material, organized as multiple long linear DNA molecules in complex with a large variety of proteins, such as histones, to form chromosomes. The genes within these chromosomes are the cell’s nuclear genome. The function of nucleus is to maintain integrity of these genes and to control activities of the cell by regulating gene expression, that is why, nucleus is called control center of the cell. Whirly-1 was identified as the 1st
nuclear protein in the nucleus and plastids of barley plant cells, which is used to analyze
the sub-cellular location of the native protein (Krause and Krupinska, 2009; Grabowski
et al., 2008).

Figure 1.9. The diagram of eukaryotic cell nucleus is showing the ribosome-studded double membranes
of the nuclear envelope, the DNA (complexes as chromatin) and the nucleolus. Within the cell nucleus, a
viscous liquid is called nucleoplasm, similar to the cytoplasm found outside the nucleus.

It houses the cell’s chromosomes and is the place where almost all DNA replication
and RNA synthesis (transcription) occur. The nuclear envelope isolates and protects a
cell’s DNA from various molecules that could accidentally damage its structure or interfere
with its processing. During processing, DNA is transcribed, or copied into a special
RNA, called mRNA. This mRNA is then transported out of the nucleus, where it is
translated into a specific protein molecule. The nucleolus is a specialized region within
the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing
takes place in the cytoplasm.

Nuclear envelope and Nuclear pores

The nuclear envelope otherwise known as nuclear membrane consists of two cellular
membranes, an inner and an outer membrane, arranged parallel to one another and separated
by 10 to 50 nm. The nuclear envelope completely encloses the nucleus and separates the
cell’s genetic material from the surrounding cytoplasm, serving as a barrier to prevent
macromolecules from diffusing freely between the nucleoplasm and the cytoplasm (Figure
1.9). The outer nuclear membrane is continuous with the membrane of rough endoplasmic
reticulum (RER) and is similarly studded with ribosomes. The space between the membranes
is called the perinucleolar space and is continuous with the RER lumen.

Nuclear pores, which provide aqueous channels through the envelope, are composed
of multiple proteins, collectively referred to as nucleoporins. The pores are about 125
million daltons in molecular weight and consist of around 50 (in yeast) to 100 proteins (in
vertebrates). The pores are 100 nm in total diameter. However, the gap through which
molecules freely diffuse is only about 9 nm wide, due to the presence of regulatory
systems within center of the pore. This size allows the free passage of small water-
soluble molecules while preventing larger molecules, such as nucleic acids and larger
proteins from inappropriately entering or exiting the nucleus. These large molecules must be actively transported into the nucleus instead. Most proteins, ribosomal subunits and some RNAs are transported through the pore complexes in a process mediated by a family of transport factors known as karyopherins. Those karyopherins that mediate movement into the nucleus are also called importins, while those that mediate movement out of the nucleus are called exportins (Paine et al., 1975; Akey, 1989).

**Nuclear sap or Nucleoplasm**

The viscous liquid within nucleus is called nucleoplasm and is similar in composition to the cytosol found outside the nucleus. Though the interior of the nucleus does not contain any membrane-bound subcompartments, its contents are not uniform and a number of subnuclear bodies exist, made up of unique proteins, RNA molecules and particular parts of the chromosomes. The best known of these is the nucleolus, which is mainly involved in the assembly of ribosomes. After being produced in the nucleolus, ribosomes are exported to the cytoplasm where they translate mRNA (Feldherr, 1968).

**Chromatin network**

The cell nucleus contains majority of the cell’s genetic material in the form of multiple linear DNA molecules organized into structures called chromosomes. During most of the cell cycle, these are organized in a DNA-protein complex known as chromatin, and during cell division, the chromatin can be seen to form the well-defined chromosomes familiar from a karyotype. A small fraction of the cell’s genes is located instead in the mitochondria.

The chromatin is of two types, i.e., euchromatin, which is the less compact form of DNA and contains genes that are frequently expressed by the cell and (ii) heterochromatin, which is the more compact form, and contains DNA that are infrequently transcribed. This structure is further categorized into (i) facultative heterochromatin, consisting of genes that are organized as heterochromatin only in certain cell types or at certain stages of development and (ii) constitutive heterochromatin that consists of chromosome structural components such as telomeres and centromeres. During interphase, the chromatin organizes itself into discrete individual patches, called chromosome territories (Alberts et al., 1984; Alberts et al., 2002).

**Nucleolus**

The nucleolus is a discrete densely stained structure found in the nucleus (Figure 1.10). It is not surrounded by a membrane and is sometimes called a suborganelle. It forms around tandem repeats of rDNA, DNA coding for ribosomal RNA (rRNA). These regions are called nucleolar organizer regions (NOR). The main roles of the nucleolus are to synthesize rRNA and assemble ribosomes. The structural cohesion of the nucleolus depends on its activity, as ribosomal assembly in the nucleolus results in the transient association of nucleolar components, facilitating further ribosomal assembly, and hence, further association. This model is supported by observations that inactivation of rDNA results in intermingling of nucleolar structures (Lodish et al., 2004).
The first step in ribosomal assembly is transcription of the rDNA by a protein called RNA polymerase I, forming a large pre-rRNA precursor. This is cleaved into the subunits 5.8S, 18S and 28S rRNA. The transcription, post-transcriptional processing and assembly of rRNA occur in the nucleolus, aided by small nucleolar RNA (snoRNA) molecules, some of which are derived from spliced introns from messenger RNAs encoding genes related to ribosomal function. The assembled ribosomal subunits are the largest structures passed through the nuclear pores.

When observed under the electron microscope, the nucleolus can be seen to consist of three distinguishable regions, i.e., (i) the innermost fibrillar centers (FCs), (ii) surrounded by the dense fibrillar component (DFC), which in turn is bordered by the (iii) granular component (GC). Transcription of the rDNA occurs either in the FC or at the FC-DFC boundary, and when rDNA transcription in the cell is increased, more FCs is detected. Most of the cleavage and modification of rRNAs occur in the DFC, while the latter steps involving protein assembly onto the ribosomal subunits occur in the GC.

**Ergastic substances**

Ergastic substances are non-living materials found in cells. The living protoplasm of a cell is sometimes called the bioplasm and distinct from the ergastic substances of the cell. The latter are usually organic or inorganic substances, which are the products of metabolism and include crystals, oil drops, gums, tannins, resins and other compounds that can aid the organism in defense, maintenance of cellular structure, or just substance storage. Ergastic substances may appear in the protoplasm, in vacuoles, or in the cell wall.
The Cell Cycle

Cell cycle or cell-division cycle is the series of events that takes place in a cell leading to its division and duplication (replication). In cells without a nucleus (prokaryotes), the cell cycle occurs via a process termed binary fission. In cells with a nucleus (eukaryotes), the cell cycle can be divided into two brief periods, i.e., (i) the interphase, during which, the cell grows, accumulating nutrients needed for mitosis and duplicating its DNA and (ii) the mitosis (M) phase, during which, the cell splits itself into two distinct cells, often called daughter cells. In all eukaryotes, progression through cell cycle is controlled by cyclin dependent kinases that bind to positive regulators called cyclins (Boer and Murray, 2000).

Phases of cell cycle

The cell cycle consists of four distinct phases (Figure 1.11), i.e., (i) G1 phase, (ii) S phase (synthesis), (iii) G2 phase (collectively known as interphase) and (iv) M phase (mitosis). M phase itself is composed of two tightly coupled processes, i.e., (i) mitosis, in which the cell’s chromosomes are divided between the two daughter cells and (ii) cytokinesis, in which the cell’s cytoplasm divides in half forming distinct cells. Activation of each phase is dependent on proper progression and completion of the previous one. The cells that have stopped dividing temporarily or reversibly are said to have entered a state of quiescence called G0 phase (Alberts et al., 1994).

Figure 1.11. Schematic representation of the cell cycle. Outer ring: I = Interphase, M = Mitosis; inner ring: M = Mitosis, G1 = Gap 1, G2 = Gap 2, S = Synthesis; G0 = Gap 0, not in ring
<table>
<thead>
<tr>
<th>State</th>
<th>Phase</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiescent/Gap</td>
<td>0</td>
<td>G₀</td>
<td>A resting phase where the cell has left the cycle and has stopped dividing.</td>
</tr>
<tr>
<td>Interphase</td>
<td>1</td>
<td>G₁</td>
<td>Cells increase in size in Gap 1. The G₁ checkpoint control mechanism ensures that everything is ready for DNA synthesis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Synthesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>DNA replication occurs during this phase.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gap 2</td>
<td>G₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>During the gap between DNA synthesis and mitosis, the cell will continue to grow. The G₂ checkpoint control mechanism ensures that everything is ready to enter the M (mitosis) phase and divide.</td>
</tr>
<tr>
<td>Cell division</td>
<td>Mitosis</td>
<td>M</td>
<td>Cell growth stops at this stage and cellular energy is focused on the orderly division into two daughter cells. A checkpoint in the middle of mitosis (Metaphase Checkpoint) ensures that the cell is ready to complete cell division.</td>
</tr>
</tbody>
</table>

After cell division, each of the daughter cells begins the interphase of a new cycle. Though the various stages of interphase are not usually morphologically distinguishable, each phase of the cell cycle has a distinct set of specialized biochemical processes that prepare the cell for initiation of cell division.

**Resting (G₀ phase)**

The term *post-mitotic* is sometimes used to refer to both quiescent and senescent cells. Non-proliferative cells in multicellular eukaryotes generally enter the quiescent G₀ state from G₁ and may remain quiescent for a long time, possibly indefinitely (as is often the case for neurons). This is very common for cells that are fully differentiated. Cellular senescence is a state that occurs in response to DNA damage or degradation that would make a cell’s progeny nonviable. It is often a biochemical alternative to the self-destruction of such a damaged cell by apoptosis.

**Interphase**

Before a cell can enter cell division, it needs to prepare itself by replicating its genetic information and all of the organelles. All of the preparations are done during the interphase. Interphase proceeds in three stages, G₁, S, and G₂. Cell division operates in a cycle. Therefore, interphase is preceded by the previous cycle of mitosis and cytokinesis.

**G₁ phase**

The first phase within interphase from end of the previous M phase until the beginning of DNA synthesis is called G₁ (G indicating gap). It is also called the growth phase. During this phase, the biosynthetic activities of the cell, which had been considerably slowed down during M phase, resume at a high rate. This phase is marked by the synthesis of various enzymes that are required in S phase, mainly those needed for DNA replication. Duration of G₁ is highly variable, even among different cells of the same species.
S phase
The ensuing S phase starts when DNA synthesis commences and when it is complete, all of the chromosomes have been replicated, i.e., each chromosome has two (sister) chromatids, thus, during this phase, the amount of DNA in the cell has effectively doubled, though the ploidy of the cell remains the same. Rates of RNA transcription and protein synthesis are very low during this phase. An exception to this is histone production, most of which occur during the S phase.

G_2 phase
The cell then enters the G_2 phase, which lasts until the cell enters mitosis. Again, significant protein synthesis occurs during this phase, mainly involving the production of microtubules, which are required during the process of mitosis. Inhibition of protein synthesis during G_2 phase prevents the cell from undergoing mitosis.

Mitosis (M Phase)
The relatively brief M phase consists of nuclear division (karyokinesis) and cytoplasmic division (cytokinesis). In plants and algae, cytokinesis is accompanied by the formation of a new cell wall. The M phase has been broken down into several distinct phases, sequentially known as prophase, prometaphase, metaphase, anaphase and telophase leading to cytokinesis.

Mitosis is the process in which a eukaryotic cell separates the chromosomes in its cell nucleus into two identical sets in two daughter nuclei. It is generally followed immediately by cytokinesis, which divides the nuclei, cytoplasm, organelles and cell membrane into two daughter cells containing roughly equal shares of these cellular components. Mitosis and cytokinesis together define the mitotic (M) phase of the cell cycle- the division of the mother cell into two daughter cells, genetically identical to each other and to their parent cell.

Functions of Cells
Cell growth and metabolism
Between successive cell divisions, cells grow through the functioning of cellular metabolism. Cell metabolism is the process by which individual cells process nutrient molecules. Metabolism has two distinct divisions, i.e., (i) catabolism, in which the cell breaks down complex molecules to produce energy and reducing power and (ii) anabolism, in which the cell uses energy and reducing power to construct complex molecules and performs other biological functions. Complex sugars consumed by the organism can be broken down into a less chemically complex sugar molecule called glucose. Once inside the cell, glucose is broken down to make adenosine triphosphate (ATP), a form of energy via two different pathways, i.e., glycolysis and citric acid cycle.
Creation of new cells

Cell division involves a single cell (called a *mother cell*) dividing into two daughter cells. Eukaryotic cells usually undergo a process of nuclear division, called mitosis, followed by division of the cell, called cytokinesis. A diploid cell may also undergo meiosis to produce haploid cells, usually four. Haploid cells serve as gametes in multicellular organisms, fusing to form new diploid cells.

DNA replication or the process of duplicating genome of a cell is required every time a cell divides. Replication like all cellular activities requires specialized proteins for carrying out the job.

Protein synthesis

Cells are capable of synthesizing new proteins, which are essential for the modulation and maintenance of cellular activities. This process involves the formation of new protein molecules from amino acid building blocks based on information encoded in DNA/RNA. Protein synthesis generally consists of two major steps, i.e., transcription and translation.

Transcription is the process where genetic information in DNA is used to produce a complementary RNA strand. This RNA strand is then processed to give messenger RNA (mRNA), which is free to migrate through the cell. The mRNA molecules that bind to protein-RNA complexes are called the ribosomes located in the cytosol where they are translated into polypeptide sequences. The ribosome mediates the formation of a polypeptide sequence based on the mRNA sequence. The mRNA sequence directly relates to the polypeptide sequence by binding to transfer RNA (tRNA) adapter molecules in binding pockets within the ribosome. The new polypeptide then folds into a functional three-dimensional protein molecule.

References


The capacity to reproduce is one of the most important characteristics of all living beings. Reproduction is a process of producing offspring and is aimed to preserve individual species. This is known for self-perpetuation. There are several modes of reproduction, which vary from species to species, in available conditions. All the reproductive methods of plants are broadly classified into two types, i.e., (i) asexual reproduction (apomixis) and (ii) sexual reproduction (amphimixis). In asexual reproduction, the new individuals are produced by any means other than the fusion of sex gametes. In sexual reproduction, the gametes from male (androecium) and female organs (gynoecium) of the flower are fused to produce a zygote (Schranz et al., 2005; Rodrigues et al., 2008). Amphimixis and apomixis are the two sides of same coin (Curtis and Grossniklaus, 2007).

Asexual Reproduction

Some plants are able to reproduce without the involvement of meiosis and fusion of gametes (syngamy). Such a kind of reproduction in which the new individuals are formed without the involvement of meiosis and syngamy is called asexual reproduction or apomixis (Koltunow, 1993; Mogie et al., 2007; Whitton et al., 2008). The asexual reproduction is characterized by quick multiplication and production of genetically similar plants from the same parent (Engelstadte, 2008). Such a population produced from single individual is called clone and each member of the clone is called ramet.

In higher plants, apomixis is of two types, i.e., (i) agamospermy and (ii) vegetative propagation:
Reproduction

Agamospermy

It is the formation of new individuals by asexual reproduction without involving fusion and formation of gametes. Embryo formation does not involve meiosis and syngamy. It is of following types:

- **Adventive embryony**: In this case, one or few extra embryos are formed from a diploid cell of nucellus or integument but never from egg, e.g., *Citrus* and *Opuntia*.
- **Recurrent apomixis (recurrent agamospermy)**: A diploid embryo sac is formed which has a diploid egg or oosphere. The diploid egg grows parthenogenetically into diploid embryos, e.g., *Poa*, *Pyrus* and *Rubus*.
- **Non-recurrent agamospermy**: It is the development of embryo from haploid egg without fertilization. The formation of new individuals from an egg is called as parthenogenesis.
- **Apospory**: It involves the development of gametophyte from sporophyte directly without the formation of spores.
- **Apogamy**: It is the development of sporophyte from gametophyte without the fusion of gametes.
- **Diplospory**: In this case, the diploid embryo sac can develop directly from diploid megaspore mother cell (Noyes, 2000, 2005).

Significance of Apomixis

Citrus, mango and blackberries are the most important apomictic crop plants. As a reproductive system, it offers the possibility of indefinite propagation of especially favourable biotypes, which may be highly heterozygous or sexually sterile (Koltunow et al., 1995; Koltunow and Tucker, 2008). In obligate apomixis, this advantage is served as the expense of long-term evolutionary flexibility, which is the gift of sexuality. However, in facultative apomixes, this phenomenon is of special significance where sexual and apomictic members co-exist.

Vegetative Propagation

Plants belonging to this category propagate by any part of their body, i.e., stem, root and leaf other than seed. The structural unit if employed in place of seed is called propagule. The lower plants reproduce vegetatively through budding, fission, fragmentation, gemmae, resting buds, spores, etc. Among flowering plants, every part of the body such as roots, stems, leaves and buds takes part in vegetative propagation. The methods of vegetative reproduction may be grouped into two categories, i.e., (i) natural methods and (ii) artificial methods.

1. Natural Method of Vegetative Propagation

In this method, a portion of plant gets separated from the parent plant and develop in to a new independent plant under favourable conditions.
Roots: Modified tuberous roots (figure 1a) of sweet potato, topiaca, yam, Tinospora and Dahlia can be propagated vegetatively when planted in soil. Adventitious buds develop on ordinary roots of guava, Dalbergia sissoo, Albizia lebbeck, etc., which sprout to form new plants.

Stems: Aerial weak stems, e.g., runners and stolons give off adventitious roots at nodes. Thereafter, if connection breaks from the parent plant, the portion with newly stuck roots develops into an independent plant. Runners are specially adapted for this purpose, e.g., grasses (Figure 2.1b). Stolon is also a weak aerial shoot, which helps in vegetative propagation, e.g., Vallisneria and strawberry. Rhizomes are underground branched or unbranched stems, which are fleshy due to storage of food material and are also reproduced by vegetative propagation, e.g., banana, ginger, turmeric, etc. The suckers of mint (Figure 2.1c) and Chrysanthemum come up from the base of the erect shoot grow horizontally in soil and form new aerial shoots. Corms of Colocasia (Figure 2.1d) and Crocus have sufficient stored food and bear many adventitious buds. A bulb of garlic and Narcissus also bears a number of buds. These buds are separated from the bulb and planted in the field for next crop. Tuber of potato is a swollen apical part of an underground stem branch and bears number of nodes or eyes. Each eye bears one or many buds. New plants are produced from the buds present on eyes. Bulbils of agave, oxalis and pineapple are small, fleshy specialized buds when fall on the ground and produce new individuals.

Leaves: In some plants, adventitious buds develop on their leaves, which get detached and form new plants, e.g., Bryophyllum (Figure 2.1e), Begonia, Streptocarpus and Kalanchoe. In Bryophyllum, the notched margins of succulent leaves bear adventitious buds. These buds usually remain dormant, when the leaf is attached with plant. However, the leaves when come in contact with moist soil develop new plantlets along the margins. However, in some species of Bryophyllum, plantlets develop along the margins of intact leaves. In Begonia and Kalanchoe, adventitious buds are produced at the place of injury.

2. Artificial Methods of Propagation

Vegetative propagation is the chief method used by the plant horticulturists and florists in reproducing many ornamental and food plants. Scientists by taking into consideration the artificial methods developed certain ways to develop new plants. Various methods are discussed below:

Cutting: Cutting is separated portion of root, stem, or leaf. Leaf cuttings are used to propagate Begonia, Bryophyllum and Kalanchoe and root cuttings are used to propagate Citron and Tamarind. Stem cuttings are most commonly used for artificial vegetative propagation. About 20-30 cm long pieces of stem are planted in natural position in soil for proper sprouting. Sometimes, the stem cuttings are treated with rooting hormone (IBA or IAA) for proper development of roots. Examples of plants propagated by stem cuttings are grapes, sugarcane, rose, Bougainvillea, etc.
**Layering:** In this method, roots are induced artificially on the branches of stems while it is still attached to the parent plant for propagation. There are two common types of layering given below:

![Layering Diagram](image)

**Figure 2.1.** Vegetative propagation: (a) adventitious buds growing into new shoots in tuberous root of sweet potato, (b) runners, (c) sucker of mint, (d) corm of *Colocasia* and (e) leaf of *Bryophyllum*

**Mound layering:** In this method, the lower branch of stem is bent down and partially defoliated (Figure 2). An injury is made in the defoliated portion. The injured and defoliated portion is covered with a light layer of moist soil in such a way that the growing tip of the branch remains above the soil surface. After few days, the pegged portion develops
adventitious roots. The rooted branch is then cut, separated from the parent plant and grown into a new plant. It is the most common method of propagating herbaceous plants. The examples are jasmine, grape vine, strawberry, raspberry, cherry, etc.

**Air layering (or Goottee):** This method is commonly employed in shrubs and trees in which branching is well above the surface of soil and very hard so cannot bend to the ground. In this method, a ring of bark is removed (girdled) or a slit at an upward angle is made at the base of an aerial branch. The girdled portion is then covered with moist moss or grafting clay (2 parts clay, 1 part cow dung, some pieces of hay, cotton and water) and wrapped with a polythene sheet (Figure 2.3). The wrapped portion is called goottee. A small quantity of root hormone may also be added. The girdled portion of the branch inside the goottee develops roots within a period of a month or two. Now, the branch is cut and planted in the soil after removing the polythene. This method is used in vegetative propagation of litchi, pomegranate, orange, lemon, *Bougainvillaea*, etc.
**Grafting:** It is the most common method of vegetative propagation described by ancient gardeners long before the science of horticulture became established. It is done only in woody plants, which show secondary growth. In this method, parts of two plants are joined in such manner that they grow as one plant. Grafting is done between the two closely related dicotyledonous plants having vascular cambia. The rooted supporting portion of one plant called stock is joined with a twig of another plant called scion. Generally, the rootstock belongs to a wild variety, which is resistant to insect-pests and diseases and possesses an efficient root system for the absorption of water and minerals. The scion is derived from the plant possessing better characters, e.g., a scion of Dussehri mango is grafted on the stock of Desi mango. During grafting, about 10-30 cm long scion with all the buds intact is placed on cut end of the stock and the joint is covered with a layer of wax or clay to prevent evaporation of water or entry of pathogen (figure 4). All the buds of rooted stock must be removed time to time. Within few days, the scion and the stock become the composite plant (Figure 2.4). China produces more than half the world’s watermelons and cucumbers and approximately 20% of these are grafted. Grafting also affects the quality of vegetables (Davis et al., 2008). Examples of the plants propagated by grafting are mango, roses, apple, rubber, *Citrus*, pear, plum, peach, watermelon (Alan et al., 2007), etc.

Grafting is of four types, i.e., (i) tongue or whip grafting, (ii) wedge grafting, (iii) crown grafting and (iv) side grafting. In tongue and wedge grafting, the scion and stock have almost the same diameter, whereas, in case of crown and side grafting, the stock has more diameter than the scion.

- **Tongue or Whip grafting:** Both, the stock and scion are cut obliquely at about the same angle.
- **Wedge grafting:** A V-shaped notch is made on stock and a scion is cut into a wedge shape so that it may fit into the stock directly.
- **Crown grafting:** Several scions having wedge shaped cut are grafted on the slits at top of the stock. An old tree may be rejuvenated by this method.
- **Side grafting:** Here, single scion having wedge shaped cut is put in a lateral slit of the stock.

![Figure 2.4. Grafting](image-url)
Micropropagation or tissue culture: This is the latest method of obtaining a number of plantlets from plant tissue. Propagation of plants by culturing cells, tissues, or organ is called micropropagation. The most common technique is to take meristematic tissue from the plant and to culture it in vitro on nutrients medium supplemented with suitable growth hormones. The tissue by cell divisions grows into an unorganized mass of cells called callus. Callus further differentiates into a number of plantlets, which are further separated (subculturing) and transferred to pots or nursery beds to raise new plants. Tissue culture technique is useful in obtaining virus and disease free plants, homozygous diploids and in commercial micropropagation of orchids, carnation, *Gladiolus*, *chrysanthemum* and other ornamental plants.

Significance/Importance of Vegetative Propagation

- Vegetative propagation is the only method of reproduction in those plants, which have lost their capacity to produce seeds, e.g., banana, seedless grapes, rose, jasmine, tulips, carnation, etc.
- It is the only method of reproduction and perpetuation in plants, which do not produce viable seeds.
- It is easier and cheaper method of propagation.
- It is easier to get rid of pathogen from any part of the plant.
- Plants produced by vegetative propagation retain the characteristic of parent plant (pureline), which is not possible by sexual reproduction.
- Method like grafting permits physical and physiological leftovers of two different individuals to the best economic advantage.

Limitation of Vegetative Propagation

- The roots developed by vegetatively propagated plants are adventitious roots, which do not go deep into the soil like taproots so these provide poor anchorage to the soil.
- In vegetatively propagated plants, variability is not found.
- By this method of reproduction, neither good qualities can be introduced nor bad characters eliminated.

Sexual Reproduction

Flower is a reproductive part of the plant and is a highly specialized reproductive shoot (Figure 2.5). Each typical flower consists of four district types of member arranged in four whorls, which are calyx, corolla, androecium and gynoecium arranged one above the other, on the top of a long or short stalk. Calyx and corolla are nonessential whors or accessory whors, whereas, andeoecium and gynoecium are essential or reproductive whors as these are directly involved in reproduction. Androecium is made up of one to many stamens, and gynoecium is made up of one to many carpels (Raven *et al.*, 1999).
Figure 2.5. Vertical section of a typical flower showing all parts

Stamen (Microsporophyll)

Stamen has a stalk called as filament (Figure 2.5) and anther is the expanded head borne by the filament at its tip (Scott et al., 2004). Most of the anthers are bilobed and are called as bithecous. Each anther lobe has two pollen sacs (microsporangia). A bithecous anther has four pollen sacs and a monotheceous anther has two pollen sacs. Two anther lobes are joined by sterile tissue called as connective. Pollen grains are produced in large number in the pollen sacs.

Development of the Pollen sacs or Microsporangium

A bilobed anther develops four pollen sacs situated at four corners of the anther. Pollen sac development begins with differentiation of archesporial cells below the epidermis at four corners of young anther. These cells divide periclinaly to form outer parietal layer and inner sporogeneous layer. The cells of outer parietal layer divide by both periclinal and anticlinal divisions to form concentric layers of pollen sac wall. Epidermis is the outermost layer of microsporangium. The cells of epidermis are generally stretched and flattened (Figure 2.6a, b). It performs usual protection function. Inner to epidermis is single layered endothecium. The cells of endothecium are tangentially elongated and are having fibrous thickenings arising from their inner walls. These thickenings are of cellulose and are hygroscopic in nature, and thus, help in dehiscence of anther. The cells from where dehiscence occurs are having thin cell walls and collectively constitute stomium, i.e., dehiscence occurs through stomium. On maturity of anther, a strain is exerted on the stomium due to the loss of water by the cells of endothecium, with the result, the stomium ruptures and the anther dehisces. Generally, the mature anther dehisces by means of slits or apical pores. Inner to endothecium are the middle layers, which are variable, i.e., 1-4 or absent. Tapetum is the innermost wall layer of anther. The cells of this layer are having large nuclei and dense cytoplasm. This layer is of great physiological significance as most of the food material from outside passes through this layer (Echlin,
At maturity, these cells degenerate and provide nourishment to developing microspores or pollens inside (Papini et al., 1999). Tapetum is of 2 types, i.e., (i) amoeboid or plasmodial tapetum in which inner and radial walls break down at early stage and these cells are free in microsporangia or pollen chambers and (ii) secretary or glandular tapetum which is more common type of tapetum, which remains as such throughout. Abolition of tapetum suicide program ruins microsporogenesis (Kawanabe et al., 2006). The cells of primary sporogeneous layer divide further and give rise to diploid sporogeneous tissue.

![Structure of Anther](image1)

**Figure 2.6.** (a) Structure of transversally cut anther showing pollen sacs and connective and (b) Transverse section of young anther with its detailed view and transverse section of mature anther at the time of dehiscence

**Microsporogenesis**

Each pollen sac has many diploid pollen mother cells (microspore mother cells) which undergo meiosis to form four haploid microspores (pollen grains). The process by which each microspore mother cell divides meiotically to form four haploid microspores or pollen grains is called microsporogenesis (Figure 2.7). However, not all microspore mother cells form microspores. Some of them disintegrate and these are used up for nourishing developing embryos.

![Diagram of Microsporogenesis](image2)

**Figure 2.7.** Stages of microsporogenesis
**Dehiscence of mature anther**

The mature anther dries up due to the loss of water. Middle layers and tapetum will degrade and developing pollen grains use their products. The sterile partition wall between two pollen sacs of an anther lobe is destroyed and it forms a single chamber. Hence, at maturity, the anther has two chambers. Later on, the layer of endothecium cells also ruptures due to the loss of water. Outer wall of anther also ruptures in the region of stomium due to the pressure exerted by the mass of pollen grains.

**Microspores and pollen grains**

Microspores are uninucleate haploid and minute spores are produced in large number inside microsporangia. The mature pollen grain (Bedinger, 1992) on the other hand is partially germinated microspore representing the male gametophyte and surrounded by a two-layered wall (Figure 2.8). The outer wall is called exine and inner wall intine. Exine is further made up of two layers, i.e., outer sexine and inner nexine. Nexine is made up of sporopollenin, which is a specific type of cutin. Intine is made up of pecto-cellulose. Exine may be covered by yellowish and sticky material called as pollen kit, which helps in sticking the pollen grains to the visiting insects during insect pollination. The exine may be variously sculptured or smooth. At certain places, exine is very thin and such areas are called germpores. At the time of pollen germination, pollen tube will come outside through the germ pore. The number of germ pores varies from species to species. The usual number is between one and three. Pollen grains with one germ pore are called monocolpate and are found mainly in monocots, and pollen grains with three germpores are called tricolpate and are found in dicots. A pollen grain has vacuolated cytoplasm and one haploid nucleus. The branch of botany concerned with study of pollen grains is called palynology.

![Figure 2.8. A-B. Pollen grains and C. sectional view of a microspore](image)

**Development of Male Gametophyte**

(a) Pre-pollination development: Microspore or pollen grain formed during microsporogenesis is first gametophytic structure, and on germination, it will form a male gametophyte. Germination of pollen grain will start in the pollen sac itself and this type of germination is called precocious germination or germination in situ. First of all, the nucleus of pollen grain will shift to periphery due to the formation of a central vacuole. Now, the nucleus will undergo mitosis to form two daughter nuclei. An oblique wall is formed resulting in the formation of a smaller generative cell and a much larger vegetative
cell or tube cell. Generative cell loses its contact with the wall of microspore and comes to lie free in the cytoplasm. Vegetative cell or tube cell has vacuolated cytoplasm containing plenty of reserve food material for the developing male gametophyte. At this two celled stage, pollination will take place and further development of male gametophyte will take place on the stigma of carpel. In some plants, the generative cell may divide to form two male gametes prior to pollination. Here, pollination will take place in three-celled stage.

(b) Post-pollination development: Germinating pollen grains absorb water and nutrients of the stigmatic secretion with the help of germ pores. Due to the intake of nutrients, the vegetative cell enlarges. The intine will come outside through one of the germ pores (Figure 2.9). Tube nucleus and generative cells migrate to the pollen tube. Generative cell now divides to form two unicellular, non-motile, haploid male gametes. Pollen tube is covered by intine only. The pollen tube secretes hydrolytic enzymes, which dissolve some tissue of style so that the pollen tube may enter deep into the style. Cytoplasm in pollen tube is present at the tip. Pollen tube acts as carrier of male gametes toward the female gametophyte. Microgametophyte (mature male gametophyte) formed is thus very much reduced and gets its nourishment from tissue of the style.

Figure 2.9. A-E. Stages in development of male gametophyte

The Carpel (Megasporophyll)

Carpel is the female part of a flower and is differentiated into a terminal stigma, an elongated style and basal swollen ovary. Stigma is the receptive spot of carpel. The middle slender stalk like part is called as style and the basal swollen part is called as ovary. The ovary is an important part, which contains one, or more small roundish or oval bodies called as ovules. After fertilization, ovary forms the fruit and ovules form the seeds (Figure 2.10).

Figure 2.10. Structure of carpel and young ovule
Reproduction

The Ovule or Megasporangium

Ovule is an integumented megasporangium (Reiser and Fischer, 1993) with in which the meiosis and megaspore formation takes place. It is attached to placenta by a distinct stalk called as funicle. The place of attachment of stalk with main body of the ovule is hilum. In an inverted ovule, the funicle fuses with main body of the ovule, forming a sort of ridge, known as raphe. The main body of ovule is made up of parenchymatous tissue called nucellus or megasporangium proper. Nucellus is covered on its outer side by one or more coverings called integuments. Ovule having single integument in known as unitegmic ovule, e.g., higher dicots and ovule having two integuments is called as bitegmic ovule, e.g., monocots and lower dicots. Rarely, the ovule is tritegmic (3 integuments), e.g., Asphodelus. Ovules are without integuments in Santalum and Loranthus and such ovules are called ategmic ovules. The integuments cover entire nucellus except a small pore at upper end, which is called micropyle. It is generally formed by inner integument or by both integuments. Through micropyle, pollen tube enters the ovule. The basal swollen part from where integuments arise is called chalaz. In massive nucellus, a diploid megaspore mother cell is differentiated. It undergoes meiosis to form a row of four haploid megaspores. Out of these, three megaspores degenerate and only one megaspore, which is facing the chalazal end, survives. It divides by mitosis to form embryo sac or female gametophyte.

Megasporogenesis and Formation of Female Gametophyte

The process of formation of megaspores from megaspore mother cell is called as megasporogenesis (Figure 2.11). It occurs in nucellus when it is not completely surrounded by the integuments. In micropyle end of nucellus, a single celled archesporium differentiates which may functions directly as megaspore mother cell or may divide periclinally to form an outer parietal cell and inner sporogeneous cell. The sporogeneous cell directly behaves as megaspore mother cell. It undergoes meiosis to form four haploid megaspores arranged mostly in linear tetrad. In most of the angiosperms, only the chalazal megaspore remains functional and others will perish. This viable and haploid megaspore will form embryo sac or female gametophyte or megagametophyte (Willemse, 1984). This type of embryo sac development is called monosporic. Monosporic and eight nucleated embryo sac are called polygonum type of embryo sac (Maheshwari, 1937; Maheshwari, 1950).

Embryo sac is a large and oval structure consisting of seven cells (3-celled egg apparatus, 3-antipodal cells and a binucleate central cell). The functional haploid megaspore divides by three successive mitotic divisions. First division will result in formation of two haploid nuclei out of which one will shift towards micropyle and other will shifts to chalazal end. Second and third mitotic division will result in the formation of four haploid nuclei toward micropylar end and four haploid nuclei toward chalazal end. At micropyle end, out of four nuclei, one will form an egg in the centre and other two will form synergids (helping cells). These two synergids and egg form an egg apparatus. At chalazal end, out of four nuclei, three will form antipodal cells. One remaining nucleus from micropyle end and one remaining nucleus from chalazal end will now shift toward centre as polar nuclei which may fuse to form a diploid secondary nucleus (Figure 2.12) so a completely developed female gametophyte is 7-celled and 8-nucleated (Yang, 2006).
In *Piper*, female gametophyte development (fritillaria type) describes with highly detected three-dimensional models and two previously unknown arrangements of megaspore nuclei during early development (Madrid and Friedman, 2009).

**Pollination**

The transfer of pollen grains from opened anther of the stamen to receptive stigma of the carpel is called pollination (Figure 2.13a). Pollination may also affect the size and shape of fruit (Figure 2.13b). It is of two types, i.e., self-pollination and cross-pollination.
Self-pollination
It involves the transfer of pollen grains from anthers of a flower to the stigma of the same flower or genetically similar flower. It usually takes place in monoecious plants or in those plants bearing bisexual flowers in which both male and female sex organs mature almost at the same time. It is of two types:

Autogamy
It is the transference of pollen grains from anther of a flower to stigma of the same flower. It occurs by 3 methods:

- **Cleistogamy**: In cleistogamy, flowers never open to expose their sex organs and the pollens fall on stigma of the same flower, e.g., *Oxalis* and *Commelia bengalensis*. These flowers are bisexual, small, inconspicuous, colourless and do not secrete nectar.
- **Homogamy**: It is the condition in which anthers and stigma in bisexual flowers attain maturity at the same time, e.g., potato, sunflower and *Mirabilis* (Four O’clock).
- **Bud pollination**: Anthers and stigma of the bisexual flowers of some plants mature before opening of the buds to ensure self-pollination, e.g., wheat, rice, pea, etc.

Geitonogamy
When pollens from one flower are deposited on stigma of another flower born on the same plant is called geitonogamy.

Advantages of self-pollination

- It maintains purity of the race and avoids mixing.
- It needs next to produce large number of pollens growing.
- Chances of pollination are more.
- Flowers need not possess devices such as large and showing petals, presence of scent and nectar to attract pollinations.

Disadvantages of self-pollination

- Useful characters can not be introduced into the race.
- Less chances of production of new species and varieties.
- Progeny continually gets weaker after every generation.

Cross-pollination (Xenogamy/Allogamy)
Transfer of pollen grains from anthers of one flower to stigma of a flower of another plant of the same species is called cross-pollination. As the geitonogamy is used to denote pollination in genetically similar plants, xenogamy is used for pollination in genetically different plants. Cross-pollination is also called allogamy in contrast to autogamy for self-pollination. It takes place in both monoecious and dioecious species but dioecious species are always cross-pollinated. The main floral characteristics, which facilitate cross-pollination, are:
Herkogamy
Flowers possess some mechanical barrier on their stigmatic surface to avoid self-pollination, e.g., *Calotropis*.

Dichogamy
In bisexual flowers, anther and stigma mature at different times. It is of 2 types, i.e., (i) protogyny (when gynoecium matures earlier than androecium, e.g., chilli, okra, pearl millet, *Ranunculus*, etc.) and (ii) protandry (when androecium matures and shed pollen before gynoecium, e.g., carrot (Koul *et al.*, 1989).

Self-incompatibility
Here, the pollen grains are incapable of germination on the stigma or if germinate, their pollen tube may not reach the egg due to certain factors. This mutual inhibition is called self-incompatibility (McCubbin and Dickinson, 1997), e.g., potato, turnip, radish, mustard, etc.

Male sterility
The pollen grains of some plants are not functional. Such plants set seeds only after cross-pollination.

Heterostyly
The flowers of some plants have different lengths of stamens and styles so that self-pollination is not possible, e.g., *Primula, Linum*, etc. The agents (vectors) responsible for cross-pollination in angiosperms have been grouped into two main categories, i.e., (i) abiotic (pollination through wind current, gravity, water, etc.) and (ii) biotic (pollination through animals) as follows:

Anemophily (wind pollination)
Majority of angiospermic flowers are wind pollinated, i.e., anemophilous. It is a non-directional and wasteful process as pollens would reach right stigma only by hit or miss affair and a large number of pollen grains are lost in transit. The common examples are grasses, sugarcane, bamboo, coconut palm, maize, etc.

Hydrophily (water pollination)
Pollination brought about through the agency of water in plants especially submerged plants is termed as hydrophily. *Hydrilla, Ceratophyllum, Zostera* and *Vallisneria* (Figure 2.14) are some of the plants pollinated through water.

![Figure 2.14. Water pollination in *Vallisneria*](image)
Reproduction

Entomophily (insect pollination)
Entomophily is a mode of pollination or transfer of pollen grains from anther to stigma through the agency of insects. The flowers, which are insect-pollinated, are entomophilous. The most common insect pollinators are moths, flies, butterflies, wasps, bees, beetles, etc. The beetles are probably the oldest group of insects, which pollinated the ancient angiosperm. Among insects, bees are the most common pollinators, which pollinate about 80% of the total insect pollinated flowers (bitter gourd, cabbage and watermelon). They visit flowers to collect their food (pollens and nectar) in their pollen baskets. There is also one report of pollination system in which flower bugs are the main pollinators on the inflorescence of Macaranga of euphorbiaceae (Ishida et al., 2009).

Ornithophily (Birds pollination)
It is a mode of pollination performed by birds. The most common bird pollinators are sunbird, humming birds, crow, parrot, etc. The birds visit a large variety of flowers such as Bombax (red silk cotton), Callistimone (bottlebrush), agave, etc. Humming bird pollinates the flowers while hovering over the flowers and sucking nectar. The bird can derive about half of its body weight of nectar in a single day.

Chiropterophily (Bat pollination)
It is a mode of pollination performed by the bats. The bats are nocturnal flying mammals, which move swiftly and transport pollen grains to long distances sometimes-over 30 km. Chiropterophilous flowers produce abundant pollen grains and secrete more nectar than the ornithophilous flowers. The examples of chiropterophilous plants are, Adansonia (baobab tree) and Kigelia pinnata (sausage tree).

Advantages of cross-pollination
• Cross-pollination brings about new genotypes, which are better adapted to the changing environment.
• Several crop plants such as mustard, sunflower, cucurbits, almonds and sunflower give significantly higher yield if bees are available and cross-pollination is allowed to occur.
• Deleterious and recessive genes are eliminated
• Hybrid seeds thus produced are more vigorous.

Disadvantages of cross-pollination
• Cross-pollination is not economical as the plants waste a lot of energy, food material and accessory structures.
• It is not a source method, and a chance of non-fertilization is always there.
• It involves addition of some undesirable character or loss of some important characters.

Pollen Germination and Fertilization
The fusion of two dissimilar gametes is termed as fertilization. In angiosperms (Jenson, 1973), the fertilization is being completed as follows:
Germination of pollen grain

After being deposited on stigma, the pollen grains absorb liquid from moist surface of the stigma and expand in size. The intine protrudes out through the germ pore and forms pollen tube. It continues to elongate and makes its way down the tissues of the stigma and style. Only distal part of the pollen tube possesses living cytoplasm. Stigma plays an important role in the germination of pollen grain. The stigma secretes fluid containing liquids, gums, sugars and resins which protect the pollens and stigma from desiccation. In angiosperms, the male gametes are carried to the egg by a pollen tube. The process is called siphonogamy. After reaching the ovary, the pollen tube enters the ovule, either through micropylar end (porogamy, e.g., lily), chalazal end (chalazogamy, e.g., Casuarina species), or laterally (mesogamy, e.g., Cucurbita species). The period between pollination and fertilization varies from plant to plant. Usually, this period varies from 12 to 48 hours (Figure 2.15).

![Figure 2.15. Longitudinal section of flower showing germination of pollen grain and fertilization](image)

Gametic fusion

In normal case, one male gamete unites with egg to form zygote and second travels a little farther and that unites with secondary nucleus. The process is known as double fertilization (Figure 2.16). As the secondary male gamete fuses with the secondary diploid (2n) nucleus, producing a triploid (3n) primary endosperm nucleus, this is called triple fusion. Thus, in embryo sac, there occur two sexual fusions, i.e., (i) one in syngamy or generative fertilisation (fusion of male gamete with egg) and (ii) the other in triple fusion or vegetative fertilisation, and therefore, the phenomenon is called double fertilization.
Post-fertilization Changes

Soon after the act of double fertilization, the flower begins to lose its shine. The petals, stamens and style either fall or wither away. The calyx, however, may persist in some cases, e.g., tomato, brinjal, etc.

The major events include:

- Development of endosperm from triploid primary endosperm nucleus in the central cell of embryo sac.
- Development of embryo.
- Development of seed from ovule.
- Development of fruit from ovary.

Endosperm

Endosperm is the food-laden tissue formed during the development of angiospermic seed, which provides essential nutrients to the growing embryo and also the young seedling at the time of seed germination (Lopes and Larkins, 1993). In gymnosperms, the endosperm is haploid (n) and forms a continuation of the female gametophyte. Based on first and subsequent divisions of primary endosperm nucleus, the endosperm is of three types, i.e., (i) nuclear, (ii) cellular and (iii) helobial.

**Nuclear endosperm**

In this type, the first division and usually several of the following divisions are unaccompanied by wall formation. The nuclei may either remain free or in later stages, they may become separated by the walls. As divisions progress, the nuclei are pushed towards the periphery, thus, a large central vacuole is formed. Often, the nuclei are especially aggregated at the micropylar and the chalazal ends of the sac, and they form only a thin layer at the sides. The number of free nuclear divisions varies in different plants. It is the most common type and found in maize, cereals (Olsen et al., 2004), sunflower, etc.
**Cellular endosperm**

In the type of cellular endosperm development, the first nuclear division primary endosperm nucleus is followed by the formation of either a longitudinal or a transverse cell wall in the central cell. Subsequent nuclear divisions and wall formations result in the formation of a cellular type of endosperm, e.g., *Petunia*, *Datura*, *Balsam*, etc.

**Helobial endosperm**

This is intermediate type between the nuclear and cellular types. In this type, the first division is followed by a transverse wall resulting in a micropylar and chalazal chamber. Further divisions are generally free nuclear and may be formed by the micropylar chamber only. Helobial type of endosperm development is prevalent in monocotyledons.

**Embryo development**

The diploid zygote (oospore) undergoes a period of brief rest, which differs from species to species. During this period, there is reduction in vacuolar size but increase in cytoplasm. Ribosomes aggregate to form polyribosomes. The various steps from zygote to the formation of embryo constitute embryogeny (Davis, 1966; Johri *et al.*, 1992; Batvgina, 2006). It is different in monocots and dicots.

**Development of Dicot embryo**

- In dicots the fertilized egg or the zygote divides by transverse wall to form two unequal cells. The larger basal cell is called suspensor cell towards micropylar end of the embryo sac. The smaller terminal cell is called embryonal cell towards the chalazal end.
- The upper suspensor cell divides by transverse divisions, and lower embryonal cell divides by longitudinal wall to form 4-celled structure called as proembryo.
- The two suspensor-cells divide repeatedly by transverse divisions to form 6-19 celled suspensors (Figure 2.17).
- Terminal cell of suspensor, which is towards micropyle, is enlarged and swollen to function as haustorium. The lowest cell of suspensor is called hypophysis.
- The embryonal cell divides by second longitudinal division at right angle to the first and it is followed by transverse division to form an octant embryo (8-celled). The four terminal octants away from suspensor will form plumule and two cotyledons, while the four basal octants next to suspensor will form hypocotyls and stele of radicle.
- Periclinal division in the octant separates outer dermagen cells which divide anticlinally to form epidermis. Inner cells again divide by periclinal walls to form periblem below dermagen andplerome in the centre. Periblem will form cortex and plerome will form stele of embryo. Hypophysis divides by transverse and longitudinal divisions to form three tiers of cells. The cells of inner tier towards embryo will form radicle. Cells of middle tier will form protoderm and cells of outer tier will form root cap.
Developing embryo is globular at this stage. Cells of embryo continue to divide. Later on, due to differentiation of two cotyledons from sides, the embryo becomes heart-shaped. Plumule is in the centre of two cotyledons.

A mature dicot embryo has radicle, plumule and two cotyledons.

Figure 2.17. A-G. Stages in development of dicot embryo in *Capsella bursa-pestoris*

**Development of Monocot Embryo**

- Here, zygote divides by transverse division to form larger basal cell called suspensor cell and small terminal cell called as embryonal cell.
- The basal cell remains undivided and forms the conspicuous part of suspensor.
- The terminal embryonal cell will now divide transversely to form a 3-celled pro-embryo. The lower most cell of pro-embryo, which is towards chalazal end, divides many times to form a single terminal cotyledon. The middle cell divides many times to form part of suspensor, plumule, radicle, etc.
- Mature monocot embryo has single terminal cotyledon, lateral plumule and a radicle.

**Seed**

Double fertilization in angiosperms triggers the transformation of ovule into a seed (Dure, 1975; Goldberg *et al.*, 1994). During embryogenesis, the endosperm may persist or completely digested (Figure 2.18). The seeds having copious amount of endosperm tissue are albuminous (wheat, corn, onion, palms, etc.). The seeds in which endosperm is used up are exalbuminous (bean, pea, gram, etc.). The outer integument of ovule becomes hard and forms outer seed coat testa, and inner integment if persists forms the inner seed coat tegmen. The nucellus when persists is called perisperm. The micropyle remains in the form of a fine pore on surface of the seed. Funicle is transformed into stalk of the seed. The hilum marks the point of attachment to the stalk.
Fruit

A true fruit is formed as a result of cell division, expansion and differentiation in the ovary (Figure 2.19). The ovary is transformed into fruit as a result of stimuli received from pollination as well as from developing seeds. After receiving necessary stimuli, the ovules are transformed into seeds and the wall of the ovary is transformed into pericarp (fruit wall). The growth of fruit is generally fast, e.g., an ovary of pumpkin shows a 20 folds increase in size just in two weeks time.

References


