# COURSE GUIDE

**AGR 206 CROP ANATOMY, TAXONOMY AND PHYSIOLOGY (2 UNITS)**

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## INTRODUCTION

Crop anatomy, taxonomy and physiology (AGR 206) is a two (2)-credit unit course on the anatomy, taxonomy and physiology of crops. The course is broken into 23 units in all in nine (9) modules. These units will teach and explain taxonomy, anatomy and physiology study as a tool and systematic process for ensuring that physiology considerations are taken into account in all proposed activities. This course guide defines what the course is all about as well as the course material that you will need to consult to ensure that the course is simple and within your reach. It suggests some general guidelines for the amount of time you are likely to spend studying each unit in order to complete it successfully. It also gives you some guidance on your tutor marked assignments. The course will deal with the basic principles and selected applications of physiology for agricultural crops, emphasizing the need for a different type of agriculture, in order to support the increasing needs for food (quantity and quality) facing climatic changes as well as increased abiotic and biotic stress conditions. The basic tools for anatomy and physiology will be evaluated.

## WHAT YOU WILL LEARN IN THIS COURSE

This course guide tells you briefly what the course is about, what course materials you will be using and how you are to use them.

## COURSE AIMS

The aim of this course is to provide a good understanding of biodiversity, genetic diversity and the levels biodiversity and their losses; the biotechnological process of preserving the genetic materials, their management and appropriation.

## COURSE OBJECTIVES

In addition to the aims above, this course sets to achieve some objectives. After going through this course, you should be able to:

- Explain the general knowledge about plant taxonomy and anatomy
- Explain the history of microscopy and different parts of compound microscopes.
- State the different techniques of anatomy like sectioning and staining.

- Explain Mounting media and mounting techniques.
- Explain the common stains for plant cells
- State the root structures and its functions in plant growth
- Explain the anatomical features of the roots
- Explain the shoot anatomy
- State the main functions of the stem
- Differentiate between dicot and monocot stems
- Discuss the leaf anatomy
- State the general characteristics of leaves
- Differentiate between dicot and monocot leaves
- Explain the meaning of plant cell
- Give different definitions of plant cell
- Outline different types of plant cell
- Describe various organelles associated with plant
- State the history of evolution of crop physiology through various stages.
- Outline the importance of crop physiology in agriculture
- Explain the effect of photoperiod on flowering in plants
- Discuss the effect of quality of light and phytochrome on flowering
- Practical utilization / application of photoperiodism and vernalization
- Explain the meaning of mineral nutrition and the classification of essential elements into two groups
- Discuss the criteria of essentiality of mineral elements
- List the specific roles of essential mineral elements
- Explain the physiology of nutrient uptake
- Explain the general account of plant hormones
- Discuss the physiological effect of Auxin, Gibberellin, Cytokinin, Abscissic acid and Ethylene
- Differentiate between cell differentiation and its processes
- Explain the Meaning and Definition of Photosynthesis
- Discuss translocation mechanism
- Explain the environmental factors affecting transpiration rates
- Distinguish between root pressure and transpiration pull
- Explains seed dormancy and its importance
- Discuss the types of dormancy

- Explain the techniques for breaking different types of dormancy
- Discuss the factors affecting germination
- Explain the concept "Mobilization of energy and food reserves in germination''
- Discuss basic idea of morphogenesis and concept of differentiation
- Explain the different morphogenetic factors and how they affect morphogenesis of plants
- Explain the term ''microsporogenesis"?
- Define apomixes and parthenogenesis etc.
- Explain polyembryony and on what basis it can be classified into different types?
- Discuss parthenocarpy

## WORKING THROUGH THIS COURSE

The ideas have been carefully put together to ensure that adequate explanations are made to enhance better understanding of the course. You are therefore, encouraged to spend quality time to study this course and ensure that you attend tutorial sessions where you can ask questions, assess your understanding of concepts and compare your knowledge with that of your classmates.

## COURSE MATERIALS

You will be provided with the following:

i. Course guide
ii. Eight (9) modules of content of twenty-three (23) units
iii. Recommended textbooks and lists of reference materials.

### STUDY UNITS

There are twenty three (23) study units in this course. This is arranged as follows:

**Module 7 Seed Germination and Dormancy**

Unit 1 Seed Dormancy: Causes and Types
Unit 2 Seed Germination

**Module 8 Plant Morphogenesis and Morphogenetic Factors**

Unit 1 Basic idea of morphogenesis and concept of differentiation
Unit 2 Morphogenetic factors

**Module 9 Embryology**

Unit 1 Male Gametophyte
Unit 2 Female Gametophyte
Unit 3 Fertilization and Post Fertilization

Each unit includes a table of contents, introduction, specific objectives, recommended textbooks and summaries of key issues and ideas. At intervals in each unit, you will be provided with a number of exercises or self-assessment exercises. These are to help you test yourself on the material you have just covered or to apply it in some way. The value of these self-tests is to help you gauge your progress and to reinforce your understanding of the material. At least one tutor-marked assignment will be provided at the end of each unit. The exercises and the tutor-marked assignments will help you in achieving the stated learning objectives of the individual units and of the course.

**RECOMMENDED TEXTS:**

More recent publications are recommended for further reading.


- Taiz, L. and Zeiger, E. In: Plant Physiology, 3rd ed. Lincoln Taiz and Eduardo Zeiger. (eds). Paniona Publishing Corporation: New Delhi, 2003
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- Medvedev, S.S. (2011). Mechanisms and physiological role of polarity in plants. *Russian Journal of Plant Physiology* 59:502-514.
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- Elaine Lopes Pereira Nunes, Cleusa Bona, Maria Cecı´lia de Chiara Moc¸o and Alessandra Ike Coan. (2009) Release of developmental constraints on tetrad shape is confirmed in inaperturate pollen of *Potamogeton*. *Annals of Botany*. Page 1 of 5 doi:10.1093/aob/mcp160, available online at www.aob.oxfordjournals.org
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## ASSESSMENT

There are two components of assessment for this course. These are:

i. Tutor-Marked Assignments (TMA's)
ii. End of course examination

## TUTOR-MARKED ASSIGNMENT (TMA)

The tutor-marked assignment (TMA) is the continuous assessment component of your course. It accounts for 30% of the total score. The TMAs must be answered before you are allowed to sit for the end of course examination. Thus, it is expected of you to apply information, knowledge and techniques obtained from the course. The TMAs would be returned after you have done the assignment.

## FINAL EXAMINATION AND GRADING

The examination concludes the assessment for the course. To prepare for this examination, revise all the areas covered in the course. Revision of all the exercises and the tutor-marked assignments before the examination will also be of help to you. The revision should start after you have finished studying the last unit. This examination constitutes 70% of the whole course. You will be informed of the time for the examination. It may or not coincide with the university semester examination.

## SUMMARY

AGR 206 intends to introduce you to Crop Anatomy, taxonomy and physiology. By the time you complete studying this course, you will be able to answer the following questions:

1. Explain the aims of plant anatomy?
2. Plant taxonomy is synthesized into four fields, what are they?
3. In details, what is plant classification
4. What is sectioning?
5. What is staining?
6. Draw a well labelled diagram of compound microscopes and define its different parts.
7. Define the different types of stains and their nature used in plant anatomy?
8. Define the anatomy of dicot stem in detail.
9. Compare the anatomical features of dicot and monocot shoot
10. What is the function of epidermis?
11. How can you identify either dorsiventral or isobilateral leaf?
12. Give different definitions of plant cell
13. Outline and explain different types of plant cell
14. Give Descriptions and functions of any five plant organelles
15. Experiments on Plant Nutrition and Transportation
16. Discuss the Current Research on Cellular and Molecular Plant Physiology
17. Explain the Current research and molecular plant physiology
18. What is photoperiodism? Classify plants based upon their photoperiodic requirement for flowering?
19. Define devernalization. How it can be achieved?
20. Briefly discuss the Mineral availability shows an interesting dose effect
21. List the Specific roles of essential mineral elements
22. Explain the Physiology of Nutrient Uptake
23. Name a hormone that is related with xylem differentiation.
24. What is cell differentiation
25. Explain the concept of photorespiration

26. Outline the Concept of photophosphorylation
27. Define translocation? Why translocation is necessary for plants?
28. Explain with examples Transpiration
29. Mention and explain the techniques for breaking different types of dormancy
30. Explain mobilization of energy and food reserves in respect to germination
31. Enlist few applications of plant tissue culture?
32. Mention the significance of vernalization in horticulture?
33. What are the pre-pollination and post pollination steps in male gametophyte development
34. Explain the patterns of megasporogenesis and megagametogenesis in Angiosperms.
35. What comes in post fertilization developments?

The questions are inexhaustible. There are many more you can answer. We wish you luck and success with the course and hope you will find it both helpful and interesting.

Best wishes!

## MODULE 1 PLANT TAXONOMY AND ANATOMY



## UNIT 1 MEANING OF PLANT TAXONOMY AND ANATOMY

**CONTENTS**



### 1.0 INTRODUCTION

Plant taxonomy is the science that finds describes, classifies, identifies and names plant. It is thus one of the main branches of taxonomy. Systematics deals with the scientific study of interrelationship, taxonomy, identification, nomenclature, classification, diversity and differences between crops.

Plant anatomy is the study of the tissue and cell structure of plant organs. The term *anatomy*, as applied to plants, generally deals with structures that are observed under a high-powered light microscope or electron microscope. (In zoology, the term *anatomy* refers to the study of internal organs; *histology* is the study of cells and tissues of animals.)

Taxonomy is one aspect of systematics that is concerned with the study of principles, procedures, rules, regulations and it is the bases of classification. In taxonomic studies the group of any rank is termed as taxon.

Plant taxonomy has two aims:

a) Identify all kinds of plants; this requires making a complete inventory of all plants. In scientific work it is essential to apply names with precision because the validity of research depends on correct identification of materials involved.

b) To arrange the kind of plant in a scheme of classification that will show their true relationship.

To be able to achieve this, the taxonomist must utilize the methods and resources of the entire major fields of botanical investigation.

- The morphologist gives him an understanding of form and structure.
- The physiologist can point out the requirements for the existence of physiological species that appear identical but differ in their requirement
- The ecologist can furnish information about the relationship between plants and environment, about how environment may affect form and structure and how the effective action of the environment determines which plants will survive.
- The geneticist and cytologist contribute information concerning inheritance and reproduction as well as chromosome and morphology.
- Biochemistry is used effectively to solve taxonomic riddles.

The nomenclatures of plants are sometimes changed. E.g. *Eupatorium odoratum* to *Chromolaena odorata*; *Voandzeia subterranean* to *Vigna subterranean.* Such changes are based on new information that will enable the taxonomist to name and classify plants according to acceptable rules of plant nomenclature.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Obtain the general knowledge about plant taxonomy and anatomy

## 3.0 MAIN CONTENTS

### 3.1 Plant Taxonomy

The science of taxonomy is a synthesis of four interested fields:

1) Systematic botany: includes genetics and cytology as well as other techniques applicable to the fields
2) Taxonomic system: includes taxonomic concepts of plant group, or texa; concepts of evolutionary sequence of characteristics; classification and arrangement of texa, description of texa or photography.
3) Nomenclature: a method of naming plants based on international rules. This permits only a single valid scientific name for each kind of plant; the discarded name is known as synonym.

4) Documentation: preservation of living or fossil flora in a museum or habarium, including type, specimen and illustration.

Plant Classification: This is the process of ordering plants into groups which are arranged in hierarchy. Each group termed taxon (plural taxa) contains items or objects with close resemblance which may be neutral or artificial. The first classification of plants were based on their economic uses, e.g. cereals, medicinal plants, oil yielding plants etc. or on gross structural resemblances e.g. herbs, shrubs, trees, climbers etc. Agronomic classification: Cereal or grain crops e.g. wheat, rice, maize, oat, sorghum, millet etc., Legumes for seeds (Pulses): e.g. peanut, fieldbean, fieldpea, pigeon pea, cowpea, soybean etc., Forage crops: e.g. grasses, legumes, crucifers etc. Root crops: e.g. sugarbeet, carrot, turnip, sweetpotato, cassava, yam., Fibre crops: e.g. cotton, kenaf etc. Tuber crops: e.g. potato, yam, etc. Sugar crops: e.g. sugarbeet, sugarcane etc. Vegetable crops: e.g. potato, sweetpotato, carrot etc.

An ideal system of classification should indicate the actual genetic relationship and also be within a reasonable limit of convenience for practical purpose.

## 3.2 Plant Classification

Kingdom
- Division
  - Class
    - Order
      - Family
        - Tribe
          - Genus- Plural: Genera
            - Species
              - Varieties, races, lines

All natural classification has a sound scientific basis while artificial classification is based on conveniences. In botany the following are hierarchical classes in descending order. The different hierarchies end with certain recommending letters thus: class-ae; order- ales; family-aceae; subfamilyeae. From the hierarchical arrangement, there is a relationship between the groups and the division according to the differences between them. Varieties are important for agricultural purposes. For example, yam has a specific (species) name and a generic name. The classification of yam according to its hierarchical inter-relationship is as follow:

Species- rotundata
Genus or Generic name-Dioscorea
Tribe- Dioscoreaceae
Family- Dioscoreaceae
Order- Dioscoreales
Class- Dicotyledoneae
Division- Spermatophyta
Kindom- planta

Keys: A key provides several choices of characteristics by which one can identify a plant.

**Table 1.1: Below is the list of some plant families and their local name**

| FAMILY | LOCAL EXAMPLES |
|---|---|
| Agavaceae | Sisal hemp |
| Alliaceae | *Allium cepa*, Onion |
| Amaranthaceae | Amaranthus sp. Greens |
| Anacardiaceae | *Mangifera indica*, Mango |
| Araceae | Colocasia, cocoyam |
| Bromelaliaceae | Anana – pineapple |
| Caricaceae | *Carica papaya* – Pawpaw |
| Convolvulaceae | Sweet potato |
| Dioscoreaceae | yams (Dioscorea sp.) |
| Poaceae | Maize, rice |
| Fabaceae | (Leguminoseae) Cowpea |
| Malvaceae | Cotton, Okra |
| Rubiaceae | Coffee |
| Rutaceae | Citrus (Citrus sp.) |
| Solanaceae | Tobacco |

## 3.2 Nomenclature

1) As the number of plants known to man increased, it became apparent that some form of generally acceptable set of principles had to be adopted in naming them to avoid confusion botanists adopted rules known as the international code of Professional.
2) Nomenclature may be defined as the system of naming plants, animals or other objects. In botanical nomenclature, the names given to plants are either Latin names or Latinized names taken from other languages.

Botanical Nomenclature: This rule deals with the use and application of scientific names.

### 3.2.1 Binomial Nomenclature

The Binomial system of nomenclature was started by Carolous Linnaeus (1753). In this system, the plants are given 2 names. One name is given to the genus, called generic name. The other is given to the species, the specific name. A plant therefore is underlined when printed. For example the scientific name for Yam is Diosscorea spp. underlined when written and *Dioscorea spp* italized in printed form. Based on the International code, there can only be one group of plants in the genus Dioscorea. Within each genus there can only be one group of plants in the genus Dioscorea. Within each genus there can only be one valid specific epithet esculentus, but the same specific epithet way apply to plants of different genus e.g Manihot esculentus., Abelmoscus esculentus etc. The following terminologies are generally employed in plant taxonomy.
GENERIC NAME:- This is always a noun and it is always written with a capital initial letter. It may be desciptive or the aboniginal name of plants or a name in honour of a person such as Jeffersonia sp after Thomus Jefferson or Linnea sp. For Linnaeus.

SPECIFIC NAME:- This may be any of the following;

a) An adjective agreeing with the generic name in gender, and usually indicating a distinguishing characteristic of the species or sometimes referring to a locality where the species was first discovered e.g. *Ulmus americana*, *Pennisetum americana* etc.
b) A noun such as it occurs when the species is named in honour of one or more persons e.g *Carex davissi* after Mr Davis, *Gilia piersonae* after Miss Pierson. Note the ending letters in the two names.

The names of taxa superior to genus, such as orders families and subdivision of such groups are also formed in accordance with generally accepted principles.

ORDER:- Is the major taxa immediately superior to the family. We form the name of the order by adding ales to the stem of an included generic name e.g Poales for Poa for the order including grasses.
FAMILY:- A family consists of a group of related genera. We form its name, except for a few that antedate the standardized system, by adding aceae to the stem of an included generic name e.g Rosaceae for Rosa etc.

A few family have long been designated by nauns that predate this system e.g.

**Table 1.2: List of Crops with Family, Old and New Names**

| Family name | Old name | New name |
|---|---|---|
| Grass | Gramineae | Poaceae |
| Mustard | Cruciferae | Brassicaceae |
| Pea | Leguminouseae | Fabaceae |
| Sunflower | Compositeae | Asteraceae |

SUB-FAMILY:- A major subdivision of a family and is sometimes used when the size of the family justifies it and when the included genera may be naturally so grouped. We form the name by adding oideae to the stem of an included generic name e.g. Festucoideae, for Festuca and Panicoideae for panicum.

TRIBE:- Is a subdivision of a family, subordinate to the subfamily when the taxon is employed. We form the name by adding eae to the stem of an included generic name, e.g. Festuceae from Festuca, for the Fescue tribe of the grass family.

AUTHORITY:- This refers to the name of the person(s) written after the scientific name or taxon. The authors name may be written out, but more commonly it is indicated by a standardized abbreviation. For example *Poa pratensis* (Kentucky blue grass) was first named and described by Linnaeus, he became the authority for that name and it is written as Poa pratensis, L., *Erythronium grandifloruim* Pursh.; *Lomatuim montanum* C and R. When rank of a plant is changed or when a specie is transferred from one genus to another, the name of the original author is placed in parenteses and it is followed by e.g *Abelmoschus esculentus* (Moench) L., *Medicago zatira* (L) All., Feruca foeniculacea (Nutt.) C and R.

**Table 1.3: Summary of Taxa used in classification for *Poa pretenses***

| | | |
|---|---|---|
| 1. | Kingdom | Plantae, plant kingdom |
| 2. | Division | Embryophyta, embryo plant |
| 3. | Subdivision | Phanaerogana – seed plants |
| 4. | Branch | Angiospermae |
| 5. | Class | Monocotyledoneae |
| 6. | Order | Poaceae - grass and sedges |
| 7. | Family | Poaceae – grass |
| 8. | Subfamily | Festucoideae |
| 9. | Tribe | Festuceae |
| 10. | Genus | Poa |
| 11. | Section | Protenses |
| 12. | Species | Poa pretenses |

TYPE:- Type method is used by taxonomist to achieve stabilization of taxa from species and subdivisions. The original plant on which the descriptive is based is deposited in a standard herbarium. When the original species is lost by accident, substitutes are provided and placed in the herbarium. The following are the terminologies for the type,
Method

HOLOTYPE: A particular specimen or element designated by the author which automatically fixes the application of this name.
LECTOTYPE: A specimen or element related by a competent worker from the original material studied by the author, to save as substitute for the holotype if the original material gets missing.
NEOTYPE:- A specimen selected to serve as substituete for the holotype when all material on which the name was based is missing.
ISOTYPE:- A specimen , other than the holotype, which duplicates the holotypes from the same collection, with the same locality, date and number as the holotype.
PARATYPE OR CO-TYPE:- Any specimen, other than the holotype, referred to in the original publication of the taxon.
SYNTYPE:- One of two or more specimen or elements used by the author of a taxon if no hologype was designated.
TOPOTYPE:- A specimen collected at the same locality as the halotype and therefore probably representing the same population.

CLASSIFICATION OF ANGIOSPERM- Flowering plants

The angiosperms belong to the branch – angiospermae and could be divided into 2 classes:- Monocotyledoneae and Dicotyledoneae.
MONOCOTYLEDONEAE: - This class consists of many subclasses and the important ones among them are;

1. Subclass Calyciferae – The agriculturally important order are :-
   a) Order Bromeliales:- This contain, the pineapple family Bromeliaceae which is mainly epiphytic,tropical and subtropical with densely clustered linear and usually spring toothed leaves.
   b) Order Zingiberates – This contain 2 important families; Musaeae – which is banana and plantain and ginger. Family – Zingiberaceae.
2. Subclass - Corolliferae – Agriculturally important orders are;
   a) Order – Liliales which contain lily family liliaceae which contains onion
   b) Order – Arales which contain Araceae family. Important crops from the family includes coconut palm – Cocos nucifera, date palm – Phoenix doctylifera; Royal palm- Roystonea regia; raffia palm – Raphia pedunculata etc.
3. Subclass Glumiflorae - This contains grasses and grass-like plants. Important order include;
   a) Order – poales – Annual or perennial, mostly grasslike herbs. Two families can be distinguished in this order: Cyperacea (sedges) and poaceae (grasses). Members of cyperaceae are mainly weeds. Poaceae is the most important plant family in the world and it contains all the cereals grains that serves as food for man and his animals. Table 1.4 shows common members of the grass family;

**Table 1.4: Members of the Poaceae (grass family)**

| Common Names | Scientific Names |
|---|---|
| Oats | *Avena sativa* |
| Barley- | *Hordeum vulgare* |
| Wheat | *Triticum aestivum* |
| Rice | *Oryza sativa* |
| Sugarcane | *Saccharum officinarum* |
| Sorghum | *Sorghum vulgare* |
| Maize | *Zea mays* |

| | |
|---|---|
| Millet | *Penisetum sp*. |

**Table 1.5: Members of the forage crops**

| | |
|---|---|
| *Andropogon sp* | gamba grass |
| *Panicum maximum* | guinea grass |
| *Digitaria sp* | crab grass |
| *Cynodon sp* | giant star grass etc |

## DICOTYLEDONEAE

This class contains many subclasses. Important ones among them include. Sub-class- polypetalae – contains many orders. Such as:-

a. Order paparales – contain many families such as Brassicaceae which contain mostly herbs with pungent watery juice. Members of the family include – Cabbage- Brassica oleracea, radish- Rapharues sativa; turnip – Brassica rapa.
b. Order Rosaleles – herbs, shrubs or trees with simple or compound leaves. This is one of the largest order of flowering plant and it include families such as Rosaceae, saxifragaceae, Fabaceae etc. Fabaceae are herbs, shrubs or trees. It is usually divided into three sub families:- Mimosoideae, Ceasalpiniodeae and lotoideae. Among the three only Lotoideae subfamily contain food crops which include; pea- *Pisium sativum*, sweet peas – *Lathyrus odoratus*, soyabeans- Glycine sp. It also contains important species such as clover – Trofolium sp, alfalfa – *Medicago sativa*.
c. Order geraniales: contains an important family- Rutaceae which contain aromatic trees or shrubs, important crop, include sweet orange – *Citrus sinensis,* Lemon- *Citrus limon*, grapefruit – *Citrus maxima*, citron- *Citrus medica*.
d. Order Malvales – contain Tiliaceae and Malvaceae families. Tiliaceae contain corchorus, a popular vegetable. Crops such as cotton – Gossypium sp., okra – *Abelmoscus esculentus*, Rosette- *Hibiscus sabdarifa* etc.
e. Order Sapindales – contains an important family such as Anacardiaceae which contain crops such as Anacardiaceae which contain crops such as cashew- *Anacarduim occidentale*, Mango – *Mangifera indica*.
f. Order Euphorbiales – contains only one family Euphorbiaceae which are herbs, shrubs or trees often with milk juice. Important

members of the family are; Rubber – *Hevea braziliensis*; Cassava- Manihot sp, Castor oil- *Ricinus communis*. The family also includes important ornamentals such as Euphorbia pulcherrima- poinsettia.

g.

SUBCLASS – SYMPETALAE

a. Order Scrphulariales – contain plant of various habitat but predominantly herbaceous. Important family include solanaceae which contain plants which are chiefly herbaceous, climbing and occasionally woody. Important crops in this family include; potato - Solanum luberosum, tomato – *Lycopersicon esculentum*, tobacco- *Nicotiana tubeccum*, peppers – *Capsicum frutescens* etc.
b. Order Rubiales : Important family include Rubiaceae – mostly trees or shrubs e.g coffee- Coffea arabica.
c. Order Cucurbitales – important family is cucurbitaceae and contain such vegetable crops as pumpkin- *Cucurbita pepo*, Water melon – *Citrulus lunatus*, Cucumber – *Cucumis sativus*, calabash – *Lagenaria sp*. etc.

## 4.0 SELF-ASSESSMENT EXERCISE

- Attempt to the general knowledge about plant taxonomy and anatomy

## 5.0 CONCLUSION

In this unit, it is concluded that plant anatomy can provide valuable characteristics in phylogenetic analyses, but these are less frequently acquired today than in the past. However, anatomical features, whether used directly to generate a cladogram or merely traced on an existing cladogram, can give insight into major adaptive shifts. In that sense, they are quite important in understanding different selective pressures. Anatomical and physiological traits are worthy of study at a lower taxonomic level as well, and are often correlated with adaptive strategies and ecological shifts.

## 6.0 SUMMARY

Plant anatomy refers to the detailed structure of the plant: leaf, stem, roots, flowers, and fruits, while taxonomy is one aspect of systematics that is concerned with the study of principles, procedures, rules, regulations and it is the bases of classification. In taxonomic studies the group of any rank is termed as taxon.

## 7.0 TUTOR-MARKED ASSIGNMENT

What are the aims of plant anatomy?

Plant taxonomy is synthesized into four fields, what are they?

In details, what is plant classification

## 8.0 REFERENCES/FURTHER READING

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## UNIT 2 TOOLS AND TECHNIQUES IN PLANT ANATOMY

**CONTENTS**



## 1.0 INTRODUCTION

As in all experimental sciences, research in plant anatomy depends on the laboratory methods that can be used to study cell structure and function. Many important advances in understanding cells have directly followed the development of new methods that have opened novel avenues of investigation. An appreciation of the experimental tools available to the cell biologist is thus critical to understanding both the current status and future directions of this rapidly moving area of science. The elements of the plant cell are the membrane and the protoplast. The protoplast includes the cytoplasm, the nucleus, the plastids, the mitochondria, and other organelles.

In the past, the chief objects of study in plant anatomy were the vegetative organs (stem, root, and leaf); today, attention is also given to the structure of flowers, fruits, and seeds. Within the field of plant anatomy there is:

1) Physiological plant anatomy, which is concerned with the links existing between plant structure and internal processes.
2) Ecological plant anatomy, which is the study of environmental effects on plant structure.
3) Pathological plant anatomy, which is the study of the effect of disease-producing agents of a biological, physical, and chemical character on plant structure, and
4) Comparative or systematic plant anatomy, which introduces the comparative study of representatives of the different systematic

groups (taxa) - species, genera, families, and so forth for the clarification of their phylogenetic bonds.

The basic method used in plant anatomy, or the study of internal plant structure, is the preparation of thin slices which are studied microscopically. From this the science “derives its name (in Greek, *anatome* means “dissection”). The emergence of the field of plant anatomy is closely related to the invention and perfection of the microscope. The English physicist R. Hooke observed in 1665 the cellular structure of thin slices of cork, elder pith, and wood from various plants, using a microscope of his own improved design.

The real founders of plant anatomy, however, are considered to be the Italian biologist M. Malpighi and the English botanist N. Grew, who published the first (1675–79) and the second (1682) works on this subject; in these works the results of a systematic microscopic study of plant material were presented. Further development came only at the beginning of the 19th century. The German scientist J. Moldenhawer in 1812 and the French researcher R. Dutrochet in 1824 were able to divide plant tissue into its component cells through maceration (soaking). In 1831 the English botanist R. Brown observed the cell nucleus; this achievement, in combination with the studies of the German botanist M. J. Schleiden, played a great role in the founding of cellular theory, whose author was the German biologist T. Schwann (in 1839). Great contributions to the field of plant anatomy were made by the French biologist Edward. van Tieghem and the German biologists Antony de Bary, Carl Von Nageli, K. Sanio, J. Hanstein, and S. Schwendener.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- To familiar with the history of microscopy and different parts of compound microscopes.
- To learn different techniques of anatomy like sectioning and staining.
- To know Mounting media and mounting techniques.
- To explain the common stains for plant cells

## 3.0 MAIN CONTENTS

### 3.1 Tools in Plant Anatomy

The theoretical knowledge is incomplete without the practical work. Plants are easily available material for the lab studies and their study in the lab adds immense knowledge to the subject. The practical work develops the scientific outlook and makes the rational approach based on facts and figures. For a better observation and defining the anatomical features of the plants in the laboratory we use different tools and techniques.

**Practical Microscopy:** The cells of plants are quite minute and microscopic in size, so cannot be observed by naked eyes. Such objects are visible only under microscopes. Our eye has limited magnification or resolution power so unable to distinguish the objects smaller than 0.1 mm. Moreover the living cells are transparent in ordinary light and cannot be distinguished among various cellular components. The microscopes are the most important tools in the plant anatomy and their magnification power is achieved by lenses of various type. The fascinating world of microorganisms and different anatomical features would have remained unknown had the microscope not been invented.

Roger Bacon (1267) described a lens for the first time. However, his observation was not pursued immediately thereafter. In 1590 glass polishers Hans and Zacchrius Jensen constructed a crude type of simple microscope by placing two lenses together, which permitted them to see minute objects. In 1609-1610 Galileo made the first simple microscope with a focusing device and observed the water flea through his microscope. In 1617-1619 the first double lens microscope with a single convex objective and ocular appeared the inventor of which was thought to be the physicist C. Drebbel. This microscope was used to study the cells, plant and animal tissue, and also the minute living organisms. Till then, the name microscope had not been given to this device; the name „microscope‟ was first proposed by Faber in 1625. The credit of developing a compound microscope with multiple lenses goes to Robert Hooke (1665) of England. It was only after 1670 that a cloth merchant of Delft (Holland), Antony van Leeuwenhoek (1632-1723), started his hobby of making microscopes. Considerable progress was made in improving the microscope in nineteenth century.

**Compound Microscope:** A compound microscope is the primary tool in the anatomy. Therefore, a clear understanding of structure, use and manipulations of a compound microscope is a must for all students of anatomy (Fig.1).

**a. Essential parts:** The essential parts of usually used monocular compound microscope are the following:

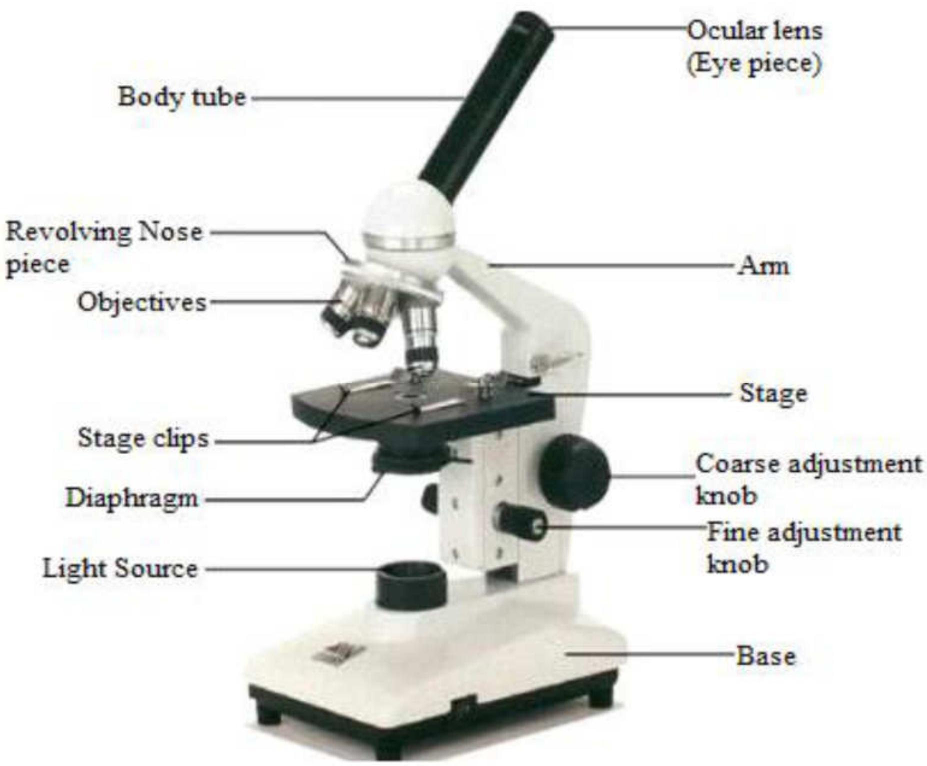


**Figure 1.1: Compound Microscope**

**Lenses:** The **eye piece** with different magnifications (5-20 times). It has field lens towards the object and eye-lens close to the observer's eye. The **objectives** generally with three different magnifications viz., low (10 X), high (40 X) and oil-immersion (97 X). The focal lengths of these are 16 mm, 4mm, and 1.6 mm respectively. These objectives are mounted on a revolving nose piece for convenience. The eye piece and objectives are fitted at the two ends of a hollow tube called the „body tube".

**Adjustment of objective lens:** In some microscopes coarse arid fine focusing adjustment knobs are both provided in order to lower or raise the body tube with lenses for rendering image clear. This is done by rotation of the knobs. The coarse adjustment is meant to bring the object into vision whereas the fine adjustment is used for focusing finer details.

**Stage:** The object to be observed is kept on a glass slides and placed on the stage. It may have clips to keep the slide in desired position or a mechanical stage for horizontal movement of the object. In some microscopes the stage may be raised or lowered with coarse and fine adjustments for focusing the object.

**Mirror:** The mirror reflects light, which is transmitted through the object for observing it. The mirror has two planes, one concave and the other plane. When natural light is available the plane mirror may be used for reflection of light because concave mirror would form window images. However, with artificial illumination, the concave mirror is necessary for higher magnification whereas for lower, the plane mirror may be used.

**Substage diaphragm:** This is meant to control the amount of light transmitted through the object.

**Substage condenser:** The substage condenser consists of convex lenses which concentrate and intensify the light reflected by-the mirror. With objectives of magnification exceeding 10X, the use of condenser becomes necessary for narrowing the core of transmitted light, which would fill the smaller aperture of the objective. The condensers usually employed are called „Abbe‟ condensers and these are used with plane mirrors.

## 3.2 Techniques in Plant Anatomy

Solid material should be sectioned in several planes in order to discover the distribution of the various tissues within it. The complete investigation of axial structures, such as stem or root, normally requires a transverse (cross) section at one, or more, levels; and radial longitudinal, and tangential longitudinal sections at different depths from the surface to the center. Foliar structures generally require transverse, and paradermal sections; and vertical longitudinal sections may occasionally be necessary. For anatomical study different techniques are used for visualizing the cells. Some of the techniques are given below.

a) **Epidermal peels:** The superficial tissues of many plant parts (especially leaves) may be peeled away in strips thin enough for microscopic examination. To make such a peel, break or cut the surface of the plant apart. Then, grip the epidermis with forceps at one of the cut edges, and pull the outer tissue layer back away from the cut. The resulting epidermal peel should be mounted in water containing a wetting agent, or in alcohol if it is very hydrophobic.

b) **Macerations:** The three-dimensional form of a cell is most easily seen when the cell is separated from the surrounding cells of the tissue. Macerating fluids accomplish this through a hydrolysis of the middle lamella. The following method is a gentle, but effective technique: Cut small pieces of the tissue into a mixture of 1 part Hydrogen peroxide, 4 parts distilled water, and 5 parts glacial acetic acid. Cook the mixture in a 56-60 degree oven for 24 hours. If further macerating is needed, replace the old fluid with a fresh mixture and cook the tissues for another 24 hours. Repeat the process until the material is mostly colorless, and may be easily teased apart with a dissecting probe. When the maceration is complete, rinse the tissues in water in an uncovered container. Stain in 0.25% Safranin in water and mount in dilute glycerin.

c) **Squashes:** Material can be squashed on a slide for cytological examination. This technique is most often used for chromosome counts and examination of mitotic structures. Dissect away non-meristematic tissues, chop the meristem with a scalpel, place a cover slip over the tissue, place paper towels on the cover slip and apply vertical pressure through your thumb.

d) **Free-Hand Sectioning:** Material should be kept moist while sectioning. Liquid should be kept on the razor blade, so that the sections float as they are cut. In general, it is inadvisable to take particular care over individual sections. Better results are usually obtained by cutting a large number of slices rapidly, and sorting out the best ones. Sections of uniform thinness are usually not necessary. Wedge-shaped slices which taper from opaque, overly thick margins to ultra-thin edges will show useable areas of the proper thickness. When cutting longitudinal sections, it is important to use a short piece of material not much longer than wide. It is impossible to cut satisfactory longitudinal sections of any considerable length by the freehand technique. Flexible structures, such as leaves, require some support during sectioning. Many leaves will yield good transverse, and vertical longitudinal sections if rolled or folded so that 10 or more thicknesses are cut at each stroke. If some extra support is necessary, the material may be inserted into the cut and of a young carrot which has been pickled in alcohol. The material and the surrounding carrot tissue are then cut at the same time. This technique should produce results superior to those of the more classical elderberry pith method. To obtain paradermal sections of a leaf, bend it over a finger and cut small slices off the curved surface. Sections of dry material should first be soaked in alcohol or hot water to soften it and remove air from the cells.

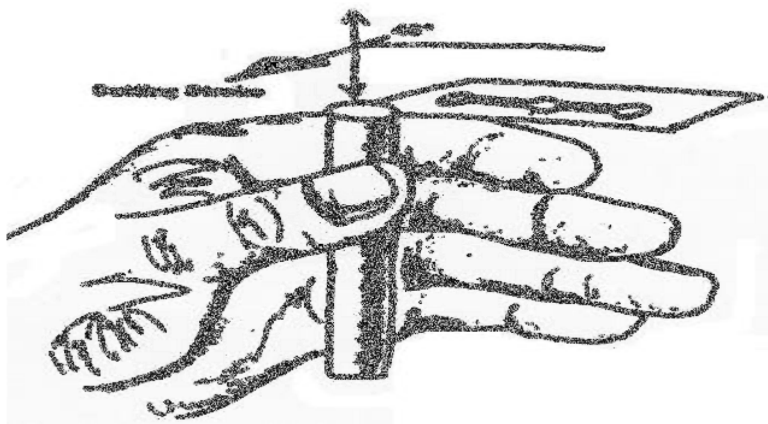

**Figure 1.2: Hand sectioning**

### 3.2.1 Steps in Sectioning

1) Obtain a new double edge razor blade. To minimize the risk of cutting oneself, cover one edge of the razor blade with masking tape. Rinse the blade with warm tap water to remove traces of grease from the surface of the blade if necessary.
2) Hold the plant material firmly. The material should be held against the side of the first finger of the left hand (or right hand) by means of the thumb (Fig.1.2). The first finger should be kept as straight as possible, while the thumb is kept well below the surface of the material out of the way of the razor edge.
3) Flood the razor blade with water this will reduce the friction during cutting as sections can float onto the surface of the blade. Take the razor blade in the right hand (or left hand) and place it on the first finger of the left hand (or right hand), more or less at a right angle to the specimen.
4) Draw the razor across the top of the material in such a way as to give the material a drawing cut (about 450 in the horizontal direction). This results in less friction as the razor blade passes through the specimen. Cut several sections at a time. Sections will certainly vary in thickness. However, there will be usable ones among the "thick" sections!

5) Transfer sections to water, always using a brush, not a forceps or needle.
6) Select and transfer the thinnest sections (the more transparent ones) onto a glass slide and stain.

**Note:** For cross sections, special care should be taken during sectioning to see that the material is not cut obliquely. During sectioning, a number of sections should be cut at the same time and one should not worry about the section thickness at this time. By slightly and progressively increasing the pressure with the razor blade on the first finger, and simultaneously exerting increasing pressure onto the specimen by the thumb, a number of sections can be cut without moving the material or the thumb. It is best to start cutting with the razor blade right at the surface of the specimen rather than against the side of the material. Since the root and stem usually have a radial symmetry, it is usually not necessary that a section should be complete, as long as it includes a portion of the tissues from the center to the outer edge of the specimen. For delicate and hard to hold specimens such as thin leaves and tiny roots, additional support can be used to facilitate hand sectioning. The following methods will allow for the sectioning of thin leaves and small, soft specimens such as roots. Tissue pieces can be inserted into a small piece of pith such as a carrot root. Once the tissue is firmly in place, the hand sectioning technique can be applied. Longitudinal sections are also difficult to obtain by hand without supporting material as small stem and root pieces are difficult to hold with one's finger. However, by cutting a v-shaped notch into the pith support, it is possible to hold the tissue firmly for free hand sections.

**Treatment of Sections:** The student should become familiar with the use of the following simple techniques and apply them in the study of laboratory materials: “Wet” water used for preparing wet mounts of specimens for general observations with a minimum of trapped air. Dilute glycerin used for preparing wet mounts for general observations when rapid drying of the mount is undesirable. Chloral hydrate is used to clear whole structures or sections which are not otherwise transparent. Mount the specimen in a few drops of chloral hydrate under a cover glass. Warm the mount over alcohol lamp until it seems more transparent. Do not allow the fluid to boil violently. Observe the mount directly, or rinse and remount in glycerin. This treatment renders cell walls visible, but removes most cell contents. Starch grains are dissolved, but crystals of calcium oxalate do not dissolve. Aniline blue used to stain callose in the phloem, and to stain nuclei and nucleoli.

When cut, sections of fresh material should be placed in water, and those of preserved materials into alcohol. However, it may be necessary to place sections of some fresh materials into alcohol to get rid of the air within them. In order to avoid unnecessary handling of the sections, all treatments should be carried out on the slides on which the sections will ultimately be mounted. When the liquid surrounding the section is to be changed, merely add a pool of the new liquid at one end of the slide. Pull the section into the new liquid with a water color brush, and pour the old liquid off the other end of the slide. Some techniques may require especially long rinses. In those cases, the sections may be rinsed more thoroughly in a shallow dish.

The best instrument for moving sections when using a dish is a small watercolor brush. Sections of preserved material should be mounted in a drop of dilute glycerin. Sections of fresh material should be mounted in water or dilute glycerin. A few air bubbles in the final mount are generally not a problem, as long as they can be recognized and do not obscure the areas of interest. The size and frequency of such bubbles may be reduced by mounting sections in water containing a wetting agent such as glycerin or detergent.

**Clearing:** This technique is especially useful for examination of the intact vascular systems of leaves and floral parts. However, it may also be resorted to as a means of making thick free hand sections more transparent. The easiest method is to clear tissue by incubating it in Ethyl Alcohol to remove hydrophobic pigments including chlorophyll. This may take several hours. Many such plant parts of either fresh, preserved or dry materials may be cleared sufficiently by warming them in chloral hydrate. Others may require treatment with NaOH as follows:

Clear in 5% NaOH in a petridish in an oven (the time varies from one to several days depending on the material). Wash 3 to 5 times in distilled water carefully with a pipette. If more clearing appears to be necessary, use a saturated aqueous solution of chloral hydrate for 24 hours. Wash again in distilled water.

### 3.2.2 Staining

The most basic reason that cells are stained is to enhance visualization of the cell or certain cellular components under a microscope. Cells may also be stained to highlight metabolic processes or to differentiate between live and dead cells in a sample. Cells may also be enumerated by staining cells to determine biomass in an environment of interest. By using different stains, one can preferentially stain certain cell components, such as a nucleus or a cell wall, or the entire cell. Most stains can be used on fixed, or non-living cells, while only some can be used on living cells, some stains can be used on either living or non-living cells. Cell staining techniques and preparation depend on the type of stain and analysis used. One or more of the following procedures may be required to prepare a sample:

a) Permeabilization: treatment of cells, generally with a mild surfactant, which dissolves cell membranes in order to allow larger dye molecules to enter inside the cell.
b) Fixation: serves to "fix" or preserve cell or tissue morphology through the preparation process. This process may involve several steps, but most fixation procedures involve adding a chemical fixative that creates chemical bonds between proteins to increase their rigidity. Common fixatives include formaldehyde, ethanol, methanol, and/or picric acid.
c) Mounting: involves attaching samples to a glass microscope slide for observation and analysis. Cells may either be grown directly to the slide or loose cells can be applied to a slide using a sterile technique. Thin sections (slices) of material such as tissue may also be applied to a microscope slide for observation.
d) Staining: application of stain to a sample to color cells, tissues, components, or metabolic processes. This process may involve immersing the sample (before or after fixation or mounting) in a dye solution and then rinsing and observing the sample under a microscope. Some dyes require the use of a mordant, which is a chemical compound that reacts with the stain to form an insoluble colored precipitate.

Botanical specimens from differing divisions (based on their taxonomy) respond to stains in a unique way. Stains that Bryophytes require might not be the same for Algae or Fungi, or even Pteridophytes. The most commons stains used in laboratory work are Aniline blue, Fast green, Safranin, Cotton blue, Methylene blue or Crystal violet. Media used for mounting may vary between Glycerine 10%, Glycerine jelly, Lactophenol, Erythrosine or Canada Balsam (or D.P.X. Mountant) depending on whether they are for temporary or permanent preparations.

#### 3.2.2.1Mixtures of Some Common Stains

**Crystal violet:**

- Crystal violet : 3 gms
- Distilled water : 80 ml
- Ethyl alcohol (95%) : 20 ml, dissolved and mixed with 0.8 gms of ammonium oxalate.

  It is a violet dye and is used to stain the lignified tissues.

**Methylene blue:**

- Methylene blue : 0.3 gms
- (0.01%) distilled water - 100 ml
- Ethyl alcohol (95%) : 30 ml, dissolved and mixed with potassium hydroxide

  It is used to stain cellulose walls.

**Safranin:**

- Safranin : 0.25 gms
- Alcohol (95%) : 10 ml
- Distilled water : 100 ml

  This is mainly used to stain lignified tissues.

**Fast Green:**

- Fast Green: 0.5 gm
- Alcohol (95%): 100c.c.

Bacteria can be divided into gram negative and gram positive bacteria. Gram"s stain is used for this purpose and help with microscopic studies of the same. Gram"s iodine solution: iodine - 1 gm, potassium iodide, 2 gms and distilled water 300 ml.

### 3.2.3 Common Biological Stains

Different stains react or concentrate in different parts of a cell or tissue, and these properties are used to advantage to reveal specific parts or areas. Some of the most common biological stains are listed below. Unless otherwise marked, all of these dyes may be used with fixed cells and tissues; vital dyes (suitable for use with living organisms) are noted.

1) **Carmine**

Carmine is an intensely red dye used to stain glycogen, while Carmine alum is a nuclear stain. Carmine stains require the use of a mordant, usually aluminium.

2) **Crystal violet**

Crystal violet, when combined with a suitable mordant, stains cell walls purple. Crystal violet is the stain used in Gram staining. Crystal violet stains the acidic components of the neuronal cytoplasm a violet color, often used in brain research.

3) **Eosin**

Eosin is most often used as a counter stain to haematoxylin, imparting a pink or red color to cytoplasmic material, cell membranes, and some extracellular structures. It also imparts a strong red color to red blood cells. Eosin may also be used as a counter stain in some variants of Gram staining, and in many other protocols. There are actually two very closely related compounds commonly referred to as eosin. Most often used is eosin Y (also known as eosin Y was or eosin yellowish); it has a very slightly yellowish cast. The other eosin compound is eosin B (eosin bluish or imperial red); it has a very faint bluish cast. The two dyes are interchangeable, and the use of one or the other is more a matter of preference and tradition.

4) **Acid fuchsine**

Acid fuchsine may be used to stain collagen, smooth muscle, or mitochondria. Acid fuchsine is used as the nuclear and cytoplasmic stain in Mallory's trichrome method. Acid fuchsine stains cytoplasm in some variants of Masson's trichrome. In Van Gieson's picro-fuchsine, acid fuchsine imparts its red color to collagen fibers. Acid fuchsine is also a traditional stain for mitochondria (Altmann's method).

5) **Haematoxylin**

Haematoxylin (hematoxylin in North America) is a nuclear stain. Used with a mordant, haematoxylin stains nuclei blue-violet or brown. It is most often used with eosin in H & E (Haematoxylin and Eosin) staining-one of the most common procedures in histology.

6) **Iodine**

Iodine is used in chemistry as an indicator for starch. When starch is mixed with iodine in solution, an intensely dark blue color develops, representing a starch/iodine complex. Starch is a substance common to most plant cells and so a weak iodine solution will stain starch present in the cells. Iodine is one component in the staining technique known as Gram staining, used in microbiology. Iodine is also used as a mordant in Gram's staining; it enhances dye to enter through the pore present in the cell wall/membrane.

7) **Methyl green**

Methyl green is used commonly with bright-field microscopes to dye the chromatin of cells so that they are more easily viewed.

8) **Methylene blue**

Methylene blue is used to stain animal cells, such as human cheek cells, to make their nuclei more observable. Also used to stain the blood film and used in cytology.

9) **Safranin**

Safranin (or Safranin O) is a nuclear stain. It produces red nuclei, and is used primarily as a counter stain. Safranin may also be used to give a yellow color to collagen.

### 3.2.4 Staining and Permanent Slide Preparation Procedure

- Deparaffinize in xylene and bring slides to 70% using a graded Ethyl alcohol series using 10, 20, 30, and 50 and than 70% solution. Coating is optional and is used only if test sections fall off the slides.
- Stain 2–24 h in safranin staining solution.
- Wash out excess stain for a few moments with distilled water. You may use running water but take care not to dislodge sections. A good technique is to run water through a flexible tube into the bottom of the staining dish.
- Dehydrate for 10 sec. in 95% Ethyl Alcohol plus 0.5% picric acid. Picric acid will cause safranin differentiation.
- Wash for 10 sec. to 1 min. (no longer) in 95% + 4 drops ammonium hydroxide per 100 ml to stop picric acid action. Excessive Ethyl Alcohol washing will completely remove Safranin staining.
- Dip briefly (10 s) in 100% Ethyl Alcohol to finish dehydration.

- Counter stain for 10-15 sec. in Fast Green staining solution. Test staining on a single slide and dilute the Fast Green solution if it is too concentrated.
- As the Fast Green staining solution evaporates with use, add additional solvent, not dye solution to maintain the correct dye concentration.
- Rinse excess Fast Green with “used clearing solution.” You can use either a Coplin jar for a few slides or a staining dish for many slides.
- Wash slides in clearing solution by dipping the sections for 5-10 sec.
- Remove clearing solution by dipping for a few moments into xylene plus 2-3 drops 100% Ethyl Alcohol (to remove residual water).
- Keep the slides in the final xylene solution while you mount the cover slip one slide at a time. Do not allow the slides to dry before mounting cover slip, because tissue damage may occur.

## 4.0 SELF ASSESSMENT EXERCISE

- Differentiate the techniques of anatomy like sectioning and staining.
- What is the difference between Mounting media and mounting techniques?
- State the common stains for plant cells

## 5.0 CONCLUSION

In this unit, it is known that in all experimental sciences, research in plant anatomy depends on the laboratory methods that can be used to study cell structure and function. Many important advances in understanding cells have directly followed the development of new methods that have opened novel avenues of investigation. An appreciation of the experimental tools available to the cell biologist is thus critical to understanding both the current status and future directions of this rapidly moving area of science. The theoretical knowledge is incomplete without the practical work. Plants are easily available material for the lab studies and their study in the lab adds immense knowledge to the subject. The practical work develops the scientific outlook and makes the rational approach based on facts and figures. For a better observation and defining the anatomical features of the plants in the laboratory we use different tools and techniques.

## 6.0 SUMMARY

Plant cells are quite minute and cannot be seen through naked eyes. For understanding the anatomical features of the plant different techniques are used such as microscopy, sectioning, staining etc. For anatomical analyses, the xylem and phloem of stems, branches, roots (root collar), rhizomes of dicots and monocots, needles, leaves and below-ground stems can be used. Microscopes are important tools for observation due to immense resolution power and the magnification of the microscope is determined by multiplying the magnification of the eyepiece by the magnification of the objective lens. In order to reveal the cellular structure plant material are being cut in various planes. Normally cross and longitudinal sections are taken for the study. These sections are stained through chemical stains and then after mounting we put them under microscope for the study. Staining is used for tissue differentiation with different types of stains which are normally chemical dyes. We can also preserve our sections by making permanent preparation of the slides.

## 7.0 TUTOR-MARKED ASSIGNMENT

1. What is sectioning?
2. What is staining?
3. What does the word "maceration" mean?
4. Draw a well labelled diagram of compound microscopes and define its different parts.
5. Define the different types of stains and their nature used in plant anatomy?
6. Define the process of mounting.

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## UNIT 3 ROOT ANATOMY

**CONTENTS**



### 1.0 INTRODUCTION

Roots are plant organs that generally function in anchorage and in absorption of water and minerals. Roots are found in the sporophytes of all land plants except for the nonvascular liverworts, hornworts, and mosses (in which the sporophytes are attached to the gametophytes), the psilotophytes (e.g., *Psilotum*), and a few other, specialized taxa. Land plants lacking roots generally have uniseriate (one-cell-thick), filamentous rhizoids that assume a similar function.

The first root to develop, in the embryo, is termed the radicle. If the radical continues to develop after embryo growth, it is known as the primary root. Additional roots may arise from internal tissue of either another root, the stem/shoot (often near buds), or (rarely) a leaf. Roots that arise from other roots are called lateral roots. Roots that arise from a nonroot organ (stem or leaf ) are called adventitious roots. Various modifications of roots have evolved, such as storage roots, aerial roots, fibrous roots, tap roots, contractile roots, haustoria, prop roots, and pneumatophores.

### 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Understand the root structures and its functions in plant growth
- Explain the anatomical features of the roots

## 3.0 MAIN CONTENTS

### 3.1 Root Anatomy

Roots, like shoots, develop by the formation of new cells within the actively growing apical meristem of the root tip (Figures 1.3 and 1.4), a region of continuous mitotic divisions. At a later age (and further up the root) these cell derivatives elongate significantly. This cell growth, which occurs by considerable expansion both horizontally and vertically, literally pushes the apical meristem tissue downward. Even later in age and further up the root, the fully grown cells differentiate into specialized cells.

Roots can be characterized by several anatomical features.

- First, the apical meristem is covered on the outside by a root cap (Figure 1.5). The root cap functions both to protect the root apical meristem from mechanical damage as the root grows into the soil and to provide lubrication as the outer cells slough off.
- Second, the epidermal cells proximal to the root tip develop hair-like extensions called root hairs (Figure 1.5); root hairs function to *greatly* increase the surface area available for water and mineral absorption.
- Third, roots have no exogenous (externally developing) organs; all lateral roots arise endogenously from the internal tissues of the root. Lateral roots grow from cell divisions of the pericycle, a cylindrical layer of parenchyma cells located just inside the endodermis, or from the endodermis itself.

Two other features of roots may or may not distinguish them from stems, as the stems of some land plants are very similar in these features to roots. All roots have a central vascular cylinder of xylem and phloem. Often, ridges of xylem alternate with cylinders of phloem (i.e., the xylem and phloem are on alternate radii). As with stems, the mostly parenchymatous region between the vasculature and epidermis is called the cortex; the center of the vascular cylinder, if vascular tissue is lacking there, is called a pith. In addition, the vascular tissue of all roots is surrounded by a special cylinder of cells known as the endodermis. In the general region of the root hairs, where most absorption takes place, each cell of the endodermis has a Casparian strip, which is a tangential band of suberin that infiltrates the cell wall (Figure 1.6).

The Casparian strip functions as a water-impermeable binding material to the plasma membrane of the endodermal cells. This forces absorbed water and nutrients to flow through the endodermal plasma membrane, as opposed to within the intercellular spaces (between the cells or through the cell wall). The function of the Casparian strips is to allow selectivity as to what mineral nutrients are and are not absorbed by the plant; e.g., toxic minerals may be selectively excluded. (Note that further away from the root apical meristem, away from root hairs, the endodermal cells become completely suberized, preventing fluid transport altogether) (Figure 1.6).

Some root anatomical specializations are found in certain taxa. For example, the aerial roots of many Orchidaceae and Araceae lack root hairs and have a multilayered epidermis called a velamen. The velamen may function in protection, prevention of water loss, or water and mineral absorption.

Roots have really important jobs, and they do not get due credit for their hard work because they remain underground all the time. Roots are responsible for:

- Anchoring the plant into the ground
- Absorbing water and nutrients
- Storing nutrients
- Associating with soil microbes in symbiotic relationships

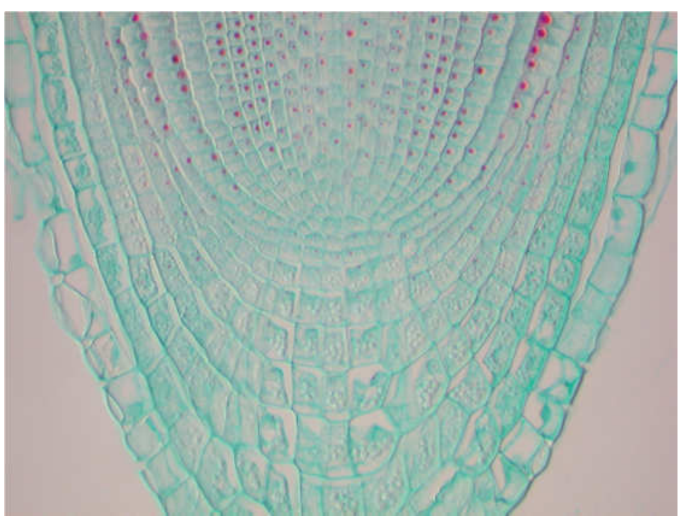

**Figure 1.3: Meristematic cells-Root. (Arrows indicate general directions of cell growth)**

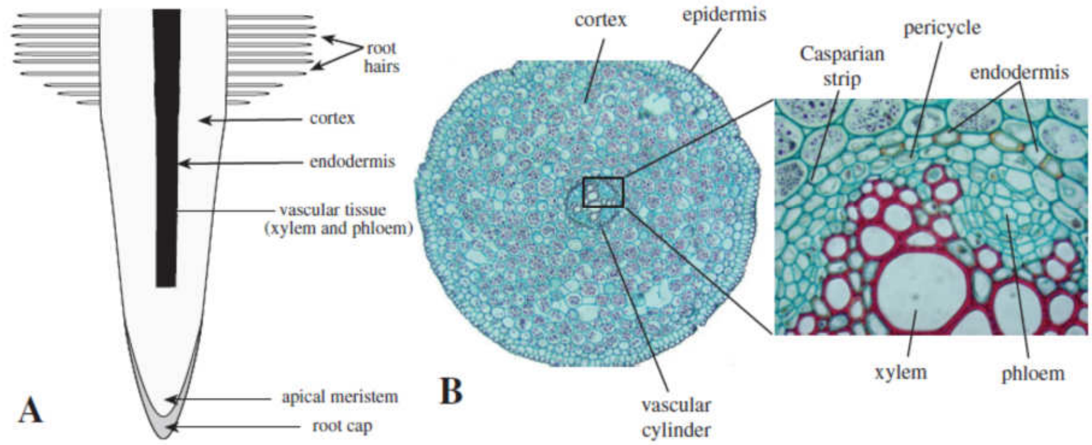


**Figure 1.4: Root anatomy. A. Root longitudinal-section. B. Root cross-section, close-up at right.**

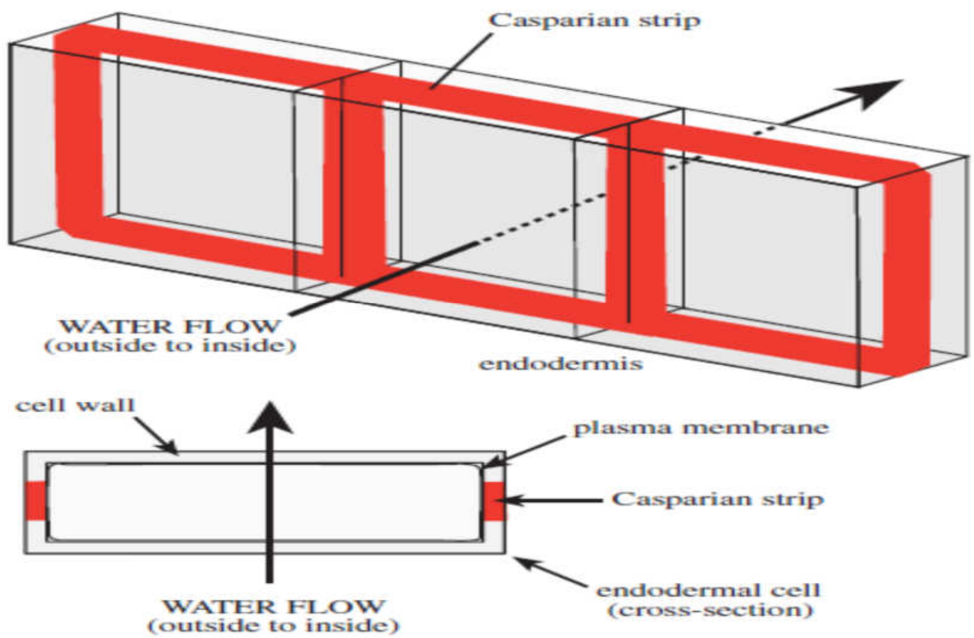


**Figure 1.5: The Casparian strip, a specialized feature of cells of the endodermis.**

## 4.0 SELF-ASSESSMENT EXERCISE

- What do you understand about root structures and its functions in pant growth
- Explain the anatomical features of the roots

## 5.0 CONCLUSION

Evolutionarily, the root seemed to be the last of the three main vegetative organs to evolve, perhaps since early land plants grew on or near the water and so much of their early innovations were geared toward maximizing photosynthesis through development of stems and leaves. There are generally two very different developmental and structural aspects to Angiosperm root systems. The primary root system is derived from the radicle and tends to be dominant in dicots, and gives rise to lateral roots with various degrees of branching. In monocots, the primary root is often ephemeral, and so adventitious roots (derived usually from stems and leaves) and seminal roots (derived from mesocotyl) comprise their root systems where they also produce lateral roots.

The root system also has an apical meristem, known as the root apical meristem. This acts in much the same way as the shoot apical meristem, causing extension growth. The main difference is the growth goes down into the ground, and roots, not leaves and branches come from the root apical meristem.

## 6.0 SUMMARY

As roots grow, they travel downward through the soil, dodging rocks and other obstacles that might be in their way. Just as you should wear a helmet when riding a motorcycle or playing hockey, roots have their own type of helmet: a root cap. The root cap protects the root apical meristem as the root pushes its way through the soil. It also secretes slimy ooze that lubricates the soil around the tip of the root, aiding the root on its journey through the harsh soil.

Anatomy of root is simpler than stem and show some characteristic features by which we can determine roots. They lack chlorophyll and are positively geotropic and they are not susceptible to light. Roots have root cap at the apex with root hairs near the apex. Vascular bundles are radial and exarch type i.e. xylem and phloem in different radii and protoxylem towards periphery and metaxylem towards center.

## 7.0 TUTOR-MARKED ASSIGNMENT

1. What are roots responsible for?
2. What are the anatomical characteristics of roots

## 8.0 REFERENCES/FURTHER READING

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## UNIT 4 SHOOT ANATOMY

CONTENTS



## 1.0 INTRODUCTION

Stems are usually above ground organs and grow towards light (positively phototropic) and away from the ground (negatively geotropic), except in the case of certain metamorphic (modified) stems. The main stem develops from the plumule of the embryo, while lateral branches develop from auxillary buds or from adventitious buds. In normal stems clearly defined internodes and nodes can be distinguished, the latter being the regions where the leaves are attached. In younger stems stomata are found in the epidermis while in the mature stems lenticels are evident. Depending on the hardness of the stem one can also distinguish between herbaceous and woody stems. In this section we will discuss the internal structures of young dicotyledonous and monocotyledonous stems, secondary thickening in the stems of dicot, and differences in the internal structures of dicots and monocots.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Explain the shoot anatomy
- State the main functions of the stem
- Differentiate between dicot and monocot stems

## 3.0 MAIN CONTENTS

### 3.1 Stem Anatomy

Stem is one of two main structural axes of a vascular plant, the other being the root. The stem is normally divided into nodes and internodes: The nodes hold one or more leaves, as well as buds which can grow into branches (with leaves, conifer cones, or inflorescences (flowers). Adventitious roots may also be produced from the nodes.
The term "shoots" is often confused with "stems"; "shoots" generally refers to new fresh plant growth including both stems and other structures like leaves or flowers. In most plants stems are located above the soil surface but some plants have underground stems.
Stems have four main functions which are:

- Support for and the elevation of leaves, flowers and fruits
- The stems keep the leaves in the light and provide a place for the plant to keep its flowers and fruits
- Transport of fluid between the root and shoot by the xylem and phloem
- Storage of nutrients

Production of new living tissue i.e. stems have cells called meristems that annually generate new living tissue. Shoots consist of stems including their appendages, the leaves and lateral buds, flowering stems and flower buds. The new growth from seed germination that grows upward is a shoot where leaves will develop. In the spring, perennial plant shoots are the new growth that grows from the ground in herbaceous plants or the new stem and/or flower growth that grows on woody plants.

In everyday speech, shoots are often synonymous with stems. Stems, which are an integral component of shoots, provide an axis for buds, fruits, and leaves. Young shoots are often eaten by animals because the fibers in the new growth have not yet completed secondary cell wall development, making the young shoots softer and easier to chew and digest. As shoots grow and age, the cells develop secondary cell walls that have a hard and tough structure. Some plants (e.g. bracken) produce toxins that make their shoots inedible or less palatable

Stem usually consist of three tissues, dermal tissue, ground tissue and vascular tissue. The dermal tissue covers the outer surface of the stem and usually functions to water proof, protect and control gas exchange. The ground tissue usually consists mainly of parenchyma cells and fills in around the vascular tissue. It sometimes functions in photosynthesis.

Vascular tissue provides long distance transport and structural support. Most or all ground tissue may be lost in woody stems. The dermal tissue in aquatic plants, stems may lack the waterproofing as found in aerial stems. The arrangement of the vascular tissues varies widely among plant species.

### 3.2 Dicot stems

Dicot stems with primary growth have pith in the center, with vascular bundles forming a distinct ring visible when the stem is viewed in cross section. The outside of the stem is covered with an epidermis, which is covered by a waterproof cuticle. The epidermis also may contain stomata for gas exchange and multicellular stem hairs called trichomes. A cortex consisting of hypodermis (collenchyma cells) and endodermis (starch containing cells) is present above the pericycle and vascular bundles (Fig. 1.6).

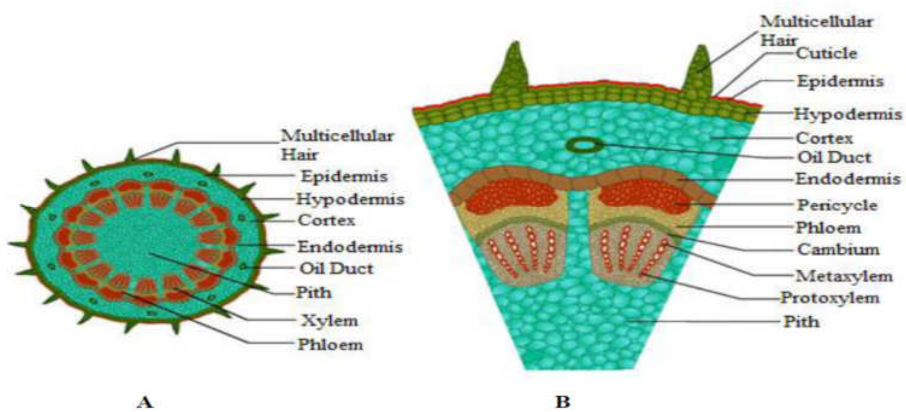


**Figure 1.6: Dicot stem; A. Diagrammatic; B. A portion enlarged**

From the study of the transverse section of the dicotyledonous stem you will identify the following three regions of tissues: epidermis, cortex and vascular cylinder or stele (Fig. 1.6).

**Epidermis:** The epidermis consists of a single layer of living cells which are closely packed. The walls are thickened and covered with a thin waterproof layer called the cuticle. Stomata with guard cells are found in the epidermis. In some stems either unicellular or multicellular hair-like outgrowths, trichomes, appear from the epidermis.

- The epidermis *protects the underlying tissues*
- The cuticle *prevents the desiccation of inner tissues* and thus *prevents water loss*
- The stomata allow *gaseous exchange* for the processes of respiration and photosynthesis

**Cortex:** This region comprises the cells of collenchyma, parenchyma and endodermis. It is situated to the inside of the epidermis. Collenchyma cells lie under the epidermis and constitute three to four layers of cells with cell walls thickened at the corners. The collenchymas cells contain chloroplasts. This tissue serves to *strengthen* the young stem. The chloroplasts are responsible for the *synthesis of organic food* during photosynthesis. Beneath the collenchyma cells are a few layers of thin-walled cells, parenchyma, with intercellular spaces. The parenchyma cells make up the bulk of the cortex. They synthesized *organic food (mainly starch)* is *stored here*. The intercellular air spaces are responsible for *gaseous exchange*.

**Endodermis:** It is starch sheath which forms the innermost layer of the cortex. This is a single layer of tightly-packed rectangular cells bordering the stele of the stem. The cells of this tissue *store starch*. It allows *solutions to pass from the vascular bundles to the cortex*.

Vascular cylinder or Stele: This region comprises the pericycle, vascular bundles and pith (medulla). The pericycle is made up of sclerenchyma cells which are lignified, dead fiber cells. These cells have thick, woody walls and tapering ends. It *strengthens* the stem. It provides *protection* for the vascular bundles. The vascular bundles are situated in a ring on the inside of the pericycle of the plant. This distinct ring of vascular bundles is a distinguishing characteristic of dicotyledonous stems. A mature vascular bundle consists of three main tissues - xylem, phloem and cambium. The phloem is located towards the outside of the bundle and the xylem towards the center. The cambium separates the xylem and phloem which bring about secondary thickening.

The xylem provides a *passage for water and dissolved ions* from the root system to the leaves. The xylem also *strengthens and supports* the stem. The phloem *transports synthesized organic food* from the leaves to other parts of the plant. The cambium, divides to produce new xylem and phloem cells, making *secondary thickening* possible.

**Pith (Medulla):** It occupies the large central part of the stem. It consists of thin-walled parenchyma cells with intercellular air spaces. Between each vascular bundle is a band of parenchyma, the medullary rays, continuous with the cortex and the pith. The cells of the pith *store water and starch*. They *allow for the exchange of gases* through the intercellular air spaces. The medullary rays *transport substances* from the xylem and phloem to the inner and outer parts of the stem.

## 3.3 Monocot stems

Vascular bundles are present throughout the monocot stem, although concentrated towards the outside. This differs from the dicot stem that has a ring of vascular bundles and often none in the center. The shoot apex in monocot stems is more elongated. Leaf sheathes grow up around it to protect it. This is true to some extent of almost all monocots. Monocots rarely produce secondary growth and are therefore seldom woody, with Palms and Bamboos being notable exceptions. However, many monocot stems increase in diameter due to anomalous secondary growth (Fig. 1.7). The tissues of dicots and monocots are basically the same as you will see. However, there are essential differences in the arrangement of the epidermis, ground tissue and vascular tissue. The structure and functions of Epidermis is same as the epidermis of the stem of a dicotyledonous plant. The epidermis consists of a single layer of living cells which are closely packed. The walls are thickened and covered with a thin waterproof layer called the cuticle. Stomata with guard cells are found in the epidermis. In some stems either unicellular or multicellular hair-like outgrowths, trichomes, appear from the epidermis. The epidermis *protects the underlying tissues*. The cuticle *prevents the desiccation of inner tissues* and thus *prevents water loss*. The stoma allows *gaseous exchange* for the processes of respiration and photosynthesis.

Ground Tissue composed of small, thick-walled sclerenchyma on the inside of the epidermis. These layers of cells are followed by larger thin-walled parenchyma cells. Intercellular air spaces are found in the parenchyma. Cortex and pith are absent. Sclerenchyma tissue *strengthens* the stem. Parenchyma tissue *stores synthesized organic food* such as starch. Intercellular air spaces allow the *exchange of gases*.

The vascular bundles are found scattered throughout the ground tissue. The vascular bundles occurring nearer the rind of the stem are smaller and are closer to one another. The vascular bundles contain no cambium and consequently secondary thickening does not occur. Thick-walled sclerenchyma fibers surround the vascular bundle. Sclerenchyma sheaths *protect the vascular* bundles and give *strength* to the stem. Large xylem vessels are found within an irregular intercellular air space called the lysigenous cavity. This space is surrounded by thin-walled parenchyma cells. Phloem is composed of thin-walled cells, viz. sieve tubes and companion cells.

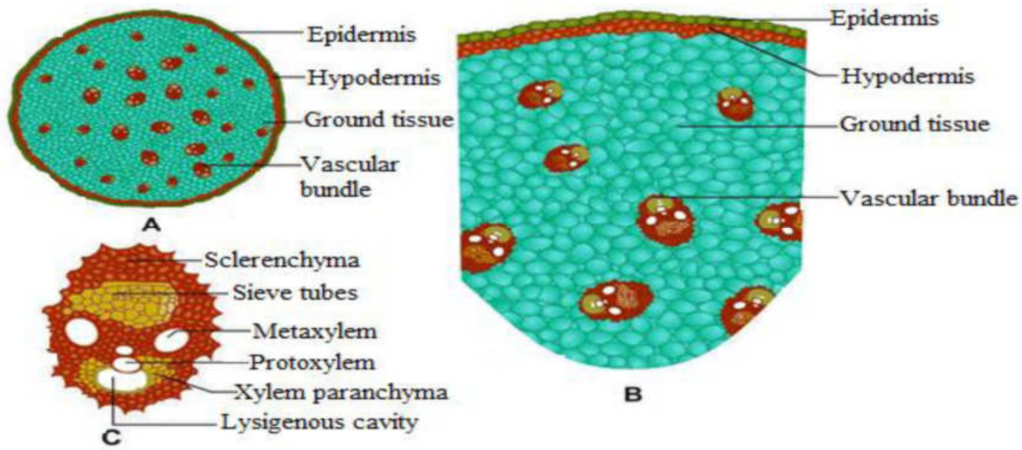


**Fig. 1.7: Monocot stem; A. Diagrammatic; B. A portion enlarged; C.Single vascular bundle**

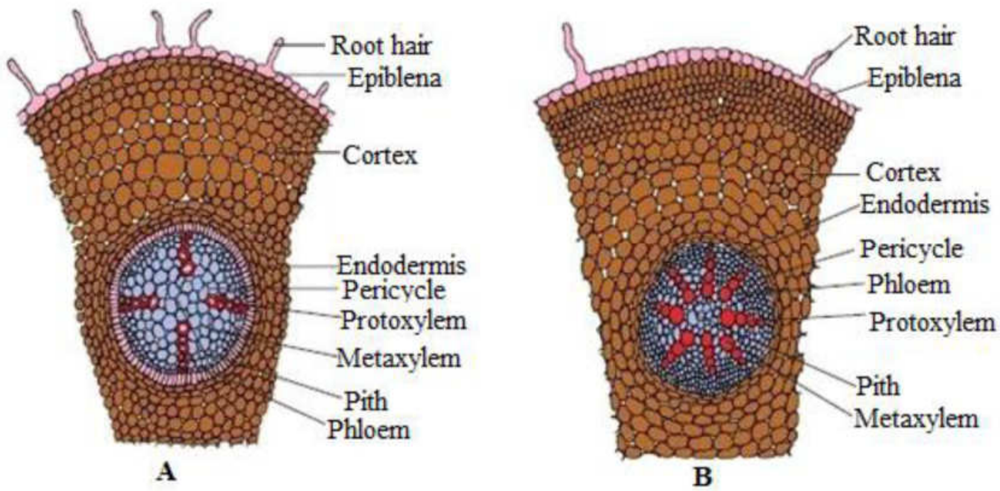


**Figure 1.8: Root; A. Dicot root; B. Monocot root**

**Table 1.6: Comparison of dicot and monocot stem anatomy**

| S/NO | Dicot Stem | Monocot Stem |
|---|---|---|
| 1. | Single layered epidermis with thick cuticle | Single layered epidermis with thick cuticle. |
| 2. | Multicellular epidermal hairs may or may not be present | Epidermal hairs absent |
| 3. | Hypodermis is generally collenchymatous | Hypodermis is generally sclerenchymatous |
| 4. | Bundle sheath absent | Bundle sheath present |
| 5. | Phloem parenchyma present | Phloem parenchyma absent |
| 6. | Vascular bundles are of similar size | Vascular bundles are of different sizes |
| 7. | No cavity in the vascular bundles | A protoxylem cavity present |

## 4.0 SELF ASSESSMENT EXERCISE

- What do you understand with the shoot anatomy?
- State the main functions of the stem
- Differentiate between dicot and monocot stems

## 5.0 CONCLUSION

A shoot is a stem plus its associated leaves. Sporophytic shoots apparently evolved twice, in the lycophytes and separately for the euphyllophytes, associated with lycophylls and euphylls, respectively (see later discussion). The leafy shootlike structures of mosses and some liverworts are gametophytic and not homologous with shoots of vascular plants.
The first shoot of a vascular plant develops from the epicotyl of the embryo. The epicotyl elongates after embryo growth into an axis (the stem), which bears leaves from its outer surface. The tip of a shoot contains the actively dividing cells of the apical meristem. As in the root, these cells undergo continuous mitotic divisions. A bit down from the apical meristem, the cells undergo considerable expansion, literally pushing the cells of the apical meristem upward (or forward). Proximal to the shoot tip, the fully expanded cells differentiate into specialized cell types.

## 6.0 SUMMARY

Stems generally function both as supportive organs (supporting and usually elevating leaves and reproductive organs) and as conductive organs (conducting both water/minerals and sugars through the vascular tissue between leaves, roots, and reproductive organs). Stems can be distinguished from roots in at least three ways. First, the apical meristem of stems is not covered by an outer protective layer (like the root cap). Second, the epidermal cells of the stem do not form structures resembling root hairs. However, the epidermal cells of stems and leaves may divide and differentiate into separate, one-to-many-celled trichomes. Third, stems bear leaves exogenously; no organs are born endogenously (except in cases of adventitious roots potentially arising from the internal parenchyma cells of stems).

Stems, particularly underground stems, may possess an endodermis similar to that of roots in structure and function. The aerial stems of many plants lack an endodermis. Numerous modifications of stems and shoots have evolved, such as bulbs, corms, caudices, rhizomes, stolons (=runners), cladodes, pachycauls, and thorns

## 7.0 TUTOR-MARKED ASSIGNMENT

1. Define the anatomy of dicot stem in detail.
2. Compare the anatomical features of dicot and monocot shoot
3. Describe in detail with diagram about the anatomy of monocot stem.

## 8.0 REFERENCES/FURTHER READING


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## UNIT 5: LEAF ANATOMY

CONTENTS



### 1.0 INTRODUCTION

A leaf is an organ of a vascular plant and is the principal lateral appendage of the stem. The leaves and stem together form the shoot. Foliage is a mass noun that refers to leaves collectively. Typically a leaf is a thin, dorsiventrally flattened organ, borne above ground and specialized for photosynthesis. Most leaves have distinctive upper (adaxial) and lower (abaxial) surfaces that differ in colour, hairiness, the number of stomata (pores that intake and output gases) and other features. In most plant species, leaves are broad and flat. Such species are referred to as broad-leaved plants. Many Gymnosperm species have thin needle-like leaves that can be advantageous in cold climates frequented by snow and frost. Leaves can also have other shapes and forms such as the scales in certain species of conifers. Some leaves are not above ground (such as bulb scales). Succulent plants often have thick juicy leaves, but some leaves are without major photosynthetic function and may be dead at maturity, as in some cataphylls, and spines). The primary site of photosynthesis in most leaves (palisade mesophyll) almost always occurs on the upper side of the blade or lamina of the leaf but in some species, including the mature foliage of *Eucalyptus* palisade occurs on both sides and the leaves are said to be isobilateral.

The leaf is the primary photosynthetic organ of the plant. It consists of a flattened portion, called the blade, which is attached to the plant by a structure called the petiole. Sometimes leaves are divided into two or more sections called leaflets. Leaves with a single undivided blade are called simple leaf, those with two or more leaflets are called compound leaf.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Explain the leaf anatomy
- State the general characteristics of leaves
- Differentiate between dicot and monocot leaves

## 3.0 MAIN CONTENTS

### 3.1 Leaf Anatomy

#### 3.1.1 General Characteristics of Leaves

Leaves are the power house of plants. In most plants, leaves are the major site of food production for the plant. Structures within a leaf convert the energy in sunlight into chemical energy that the plant can use as food. Chlorophyll is the molecule in leaves that uses the energy in sunlight to turn water ($H_2O$) and carbon dioxide gas ($CO_2$) into sugar and oxygen gas ($O_2$). This process is called photosynthesis. The internal organization of most kinds of leaves has evolved to maximize exposure of the photosynthetic organelles, the chloroplasts, to light and to increase the absorption of carbon dioxide. Gas exchange is controlled by stomata, which open or close to regulate the exchange of carbon dioxide, oxygen, and water vapour with the atmosphere. In a given square centimeter of a plant leaf there may be from 1,000 to 100,000 stomata. Some leaf forms are adapted to modulate the amount of light they absorb to avoid or mitigate excessive heat, ultraviolet damage, or desiccation, or to sacrifice light-absorption efficiency in favour of protection from herbivory.
Leaves can also store food and water, and are modified accordingly to meet these functions, for example in the leaves of succulent plants and in bulb scales. The concentration of photosynthetic structures in leaves requires that they be richer in protein, minerals, and sugars than woody stem tissues. Accordingly, leaves are prominent diet of many animals. This is true for humans, for whom leaf vegetables commonly are food staples.

Deciduous plants in frigid or cold temperate regions typically shed their leaves in autumn, whereas in areas with a severe dry season, some plants may shed their leaves until the dry season ends. In either case the shed leaves may be expected to contribute their retained nutrients to the soil where they fall.

The anatomy of leaf shows following cell composition.

**Epidermis:** A leaf is made of many layers that are sandwiched between two layers of tough skin cells (called the epidermis). The epidermis also secretes a waxy substance called the cuticle. These layers protect the leaf from insects, bacteria, and other pests. Among the epidermal cells are pairs of sausage-shaped guard cells. Each pair of guard cells forms a pore (called stoma; the plural is stomata). Gases enter and exit the leaf through the stomata. The epidermal cells are barrel-shaped, compactly arranged; upper epidermis is covered with thick cuticle and lacks stomata; lower epidermis is light green, covered with thin cuticle and is interrupted by stomata. Epidermis helps the plant by:

- The cuticle *prevents water loss*
- The epidermis *protects the internal tissues* from injury
- The stomata *allows for gaseous exchange for photosynthesis and respiration*

Since the epidermis is translucent it allows light to reach the mesophyll tissue for photosynthesis. Within the leaf, there is a layer of cells called the mesophyll. The word mesophyll is Greek and means "middle" (meso) "leaf" (phyllon). Mesophyll can then be divided into two layers, the palisade layer and the spongy layer. Palisade cells are more column-like, and lie just under the epidermis, the spongy cells are more loosely packed and lie between the palisade layer and the lower epidermis. The air spaces between the spongy cells allow for gas exchange. Mesophyll cells (both palisade and spongy) are packed with chloroplasts, and this is where photosynthesis actually occurs. This is the ground tissue. Palisade parenchyma is found immediately below the upper epidermis, 2 to 3 layered, with compactly arranged tubular cells, rich in parietal chloroplasts. Spongy parenchyma is found above the lower epidermis; these cells are varied in shapes and sizes, very loosely arranged enclosing air spaces some of which open into stomata. Chloroplasts are parietal in the parenchyma cells. Most food production takes place in elongated cells called palisade mesophyll. Gas exchange occurs in the air spaces between the oddly-shaped cells of the spongy mesophyll.

**Vascular tissue:** The vascular tissue, xylem and phloem are found within the veins of the leaf. Veins are actually extensions that run from to tips of the roots all the way up to the edges of the leaves. The outer layer of the vein is made of cells called bundle sheath cells (E), and they create a circle around the xylem and the phloem. On the picture, xylem is the upper layer of cells (G) and is shaded a little lighter than the lower layer of cells - phloem (H). Recall that xylem transports water and phloem transports sugar (food). Vascular bundles vary in size; each bundle is conjoint, collateral and closed. The vascular bundle is covered by a bundle sheath of parenchyma cells. Phloem is towards lower epidermis; xylem is towards upper epidermis, with metaxylem facing phloem. Fibers are absent in both xylem and phloem. The xylem and phloem elements are conspicuous only in large vascular bundles.

Dicot and monocot plants have different leaf morphology and anatomy and their description is given below.

**Monocot leaf:** Example: Maize.

The leaf of monocot plants is known as isobilateral and is vertically oriented.

**Epidermis:** This is uniseriate, with barrel-shaped, compactly arranged cells and is covered with thick cuticle. Stomata are found on both upper and lower epidermal layers hence it is called amphistomatic (more on the lower epidermis). Though the leaf is referred to as isobilateral, it is only in upper epidermis, a few large, empty and colorless bulliform or motor cells are present. During dry weather, these motor cells help the leaf to roll over, due to the changes in turgidity. This rolling of leaf reduces the rate of stomatal transpiration.

**Mesophyll:** There is no differentiation of mesophyll into spongy and palisade parenchyma. All the cells of chlorenchyma are alike, isodiametric, almost compactly arranged with numerous parietal chloroplasts.

**Vascular tissue:** The vascular bundles are numerous, arranged in parallel series (venation is palmate-parallel), conjoint, collateral and closed. Phloem is towards lower epidermis. Each vascular bundle is surrounded by chlorenchymatous bundle; this sheath also serves for temporary storage of starch. A few vascular bundles are larger in size, with more amounts of xylem and phloem and with large bundle sheath cells. A patch of sclerenchyma is present above and below the large sized vascular bundles (Fig. 9).

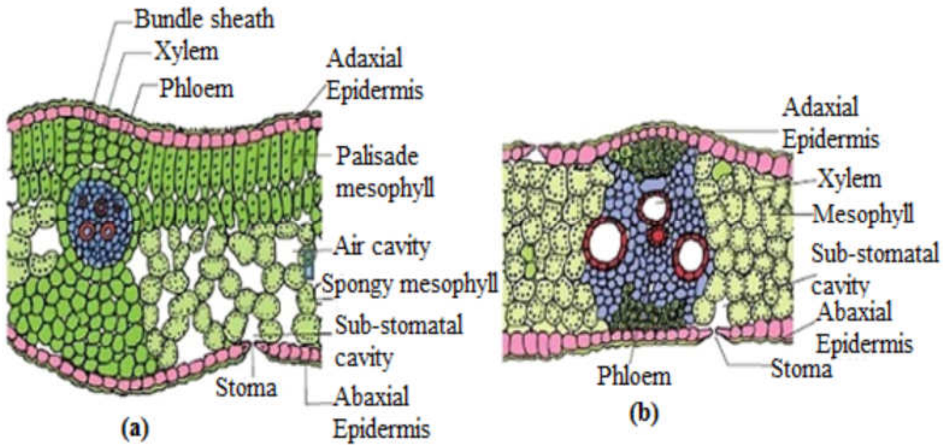


**Figure 1.9: A Dicot leaf; B. Monocot leaf**

**Dicot leaf:** Example: Sunflower

It is more strongly illuminated on the upper surface than the lower. This unequal illumination induces a difference in the internal structure between upper and lower sides. A section made at right angle to one of the bigger veins reveals following internal structures.

**Epidermis**: It is in two layers, one on each surface of the leaf. Both the layers are composed of compactly arranged, barrel-shaped cells. Intercellular spaces are absent. A cuticle surrounds both the layers. Multicellular hairs called trichomes are present on both the layers. Stomata occur only in the lower epidermis. This condition is described as hypostomatic.

**Mesophyll**: The ground tissue that occurs between the two epidermal layers. It is exclusively composed of chlorenchyma cells. The mesophyll is characteristically differentiated into two regions namely, an upper palisade parenchyma and a lower spongy parenchyma.

a) Palisade parenchyma is composed of two or three layers of elongated, compactly arranged chlorenchyma cells. Intercellular spaces are absent. The cells contain a very large number of chloroplasts. Due to this fact the upper surface seems greener than the lower surface in dorsiventral leaf.

b) Spongy parenchyma is composed of a few layers of loosely arranged spherical or oval chlorenchyma cells with prominent intercellular spaces. These cells contain very few chloroplasts. They fit closely around the vein or vascular bundle. The cells contain few chloroplasts. Spongy cells help diffusion of gases through the empty spaces left between them. They manufacture sugar and starch to some extent only.

**Vascular tissue:** Veins represent the vascular bundles. They are found irregularly scattered in the mesophyll due to reticulate venation. The largest and the oldest vein is found in the centre. It is known as midrib vein. Each vein has a bundle sheath composed of single layer of compactly arranged barrel shaped parenchyma cells. The bundle sheath encloses both xylem and phloem. Xylem is found towards upper epidermis and phloem towards lower epidermis. In the xylem many protoxylem and metaxylem vessels are found. Protoxylem orients towards upper epidermis. Hence, the vascular bundles are described as conjoint and collateral with endarch xylem. The bundle sheath of the midrib vein is connected to the upper and the lower epidermal layers by many layers of collenchyma cells, representing bundle sheath extensions or hypodermal collenchymas (Fig. 1.9).

**How can you identify dorsiventral leaf?**

- Presence of two epidermal layers
- Presence of cuticle and trichomes in both the epidermal layers
- Hypostomatic conditions
- Mesophyll differentiated into upper palisade parenchyma and lower spongy parenchyma.
- Veins irregularly scattered in the mesophyll
- Presence of a bundle sheath made up of parenchyma.
- Vascular bundles are conjoint, collateral with endarch xylem.
- Presence of bundle sheath extensions made up of collenchyma.
- Representing bundle sheath

**How can you identify isobilateral leaf?**

- Presence of two epidermal layers
- Presence of cuticle and trichomes in both the epidermal layers
- Amphistomatic condition
- Presence of motor cells in the upper epidermis
- Presence of undifferentiated mesophyll
- Vascular bundle parallel arranged
- Vascular bundle conjoint, collateral with endarch xylem
- Presence of hypodermal sclerenchyma

## 4.0 SELF ASSESSMENT EXERCISE

- Discuss leaf anatomy
- List the general characteristics of leaves
- Differentiate between dicot and monocot leaves

## 5.0 CONCLUSION

Leaves are the plant organs that function primarily in photosynthesis. However, leaves or leaflike homologs have been co-opted for innumerable other functions in plants. True leaves evolved with the development of a continuous strand of vascular tissue running from the stem into the leaf. Leaves have a characteristic development and structure. Thus, leaves have both an upper epidermis and lower epidermis. The cuticle, which is an apomorphy of all land plants, is often thickened on leaf epidermal cells. The stomate was a major innovation in the evolution of land plants. Stomates consist of two chlorophyllous guard cells, between which is an opening, the stomatal pore or stoma

## 6.0 SUMMARY

The leaf is the primary photosynthetic organ of the plant. It consists of a flattened portion, called the blade, which is attached to the plant by a structure called the petiole. Sometimes leaves are divided into two or more sections called leaflets. Leaves with a single undivided blade are called simple leaf, those with two or more leaflets are called compound leaf. Dicot leaves comprise mesophyll cells i.e. palisade and spongy parenchyma. While the monocot leaves only have spongy cells in their mesophyll.

## 7.0 TUTOR-MARKED ASSIGNMENT

1. What are the general characteristics of a leaf?
2. What is the function of epidermis?
3. How can you identify either dorsiventral or isobilateral leaf?

## 8.0 REFERENCES/FURTHER READING


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## MODULE 2 PLANT CELL: AN OVERVIEW



## UNIT 1 BRIEF OVERVIEW OF PLANT CELL

**CONTENTS**



### 1.0 INTRODUCTION

The cell (from Latin cellar, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. A cell is the smallest unit of life. Cells are often called the "building blocks of life". The study of cells is called cell biology. The cell was discovered by Robert Hooke in 1665, who named the biological units for their resemblance to cells inhabited by Christian monks in a monastery. Cell theory, first developed in 1839 by Matthias Jakob Schleiden and Theodor Schwann, states that;

1) All organisms are made up of one or more cells and the products of those cells.
2) All cells carry out life activities (require energy, grow, have a limited size).
3) New cells arise only from other living cells by the process of cell division.

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Explain the meaning of plant cell
- Give different definitions of plant cell
- Outline different types of plant cell
- Differentiate between plant cell and animal cell

## 3.0 MAIN CONTENT

### 3.1 Meaning and Definitions of Plant Cell

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Plant cells have special organelles called chloroplasts, which create sugars via photosynthesis. They also have a cell wall that provides structural support.

#### 3.1.1 Plant Cells vs. Animal Cells

Plant and animal cells are both eukaryotic cells, meaning they possess a defined nucleus and membrane-bound organelles. They share many common features, such as a cell membrane, nucleus, mitochondria, Golgi apparatus, endoplasmic reticulum, ribosomes, and more.

However, they have some apparent differences. Firstly, plant cells have a cell wall that surrounds the cell membrane, whereas animal cells do not. Plant cells also possess two organelles that animal cells lack: chloroplasts and a large central vacuole.

These additional organelles allow plants to form an upright structure without the need for a skeleton (cell wall and central vacuole), and also allow them to produce their own food through photosynthesis (chloroplasts).

**Parts of a Plant Cell**

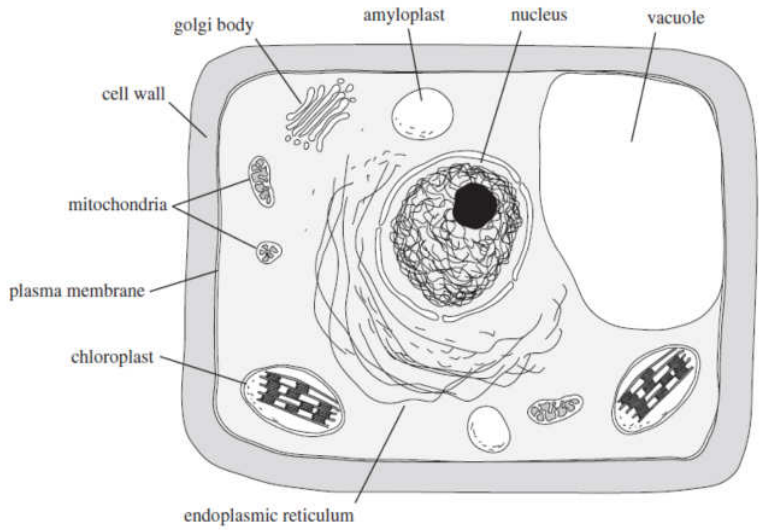


**Fig 2.1: Diagram of a Plant Cell with the Organelles Labeled**

The plant cell has many different features that allow it to carry out its functions. Each of these structures, called organelles, carryout a specialized role.

Animal and plant cells share many common organelles, which you can find out more about by visiting the "Animal Cell" article. However, there are some specialized structures in plant cells, including chloroplasts, a large vacuole, and the cell wall.

### 3.1.2 Specialized Structure in Plant Cells

- **Chloroplasts**

Chloroplasts are specialized organelles found only in plants and some types of algae. These organelles carry out the process of photosynthesis, which turns water, carbon dioxide, and light energy into nutrients from which the plant can obtain energy.

There can be over one hundred chloroplasts in certain plant cells.

Chloroplasts are disk-shaped organelles that are surrounded by a double membrane. The outer membrane forms the external surface of the chloroplast and is relatively permeable to small molecules, allowing substances entry into the organelle. The inner membrane lies just beneath the outer membrane and is less permeable to external substances. Between the outer and inner membrane is a thin intermembrane space that is about

10-20 nanometres wide. The center of the chloroplast that is enclosed by the double membrane is a fluid matrix called the stroma (you can think of this like the cytoplasm of the chloroplast).

Within the stroma, there are many structures called thylakoids, which look like flattened disks. Thylakoids are stacked on top of one another in vascular plants in stacks called grand. Thylakoids have a high concentration of chlorophyll and carotenoids, which are pigments that capture light energy from the sun. The molecule chlorophyll is also what gives plants their green colour.

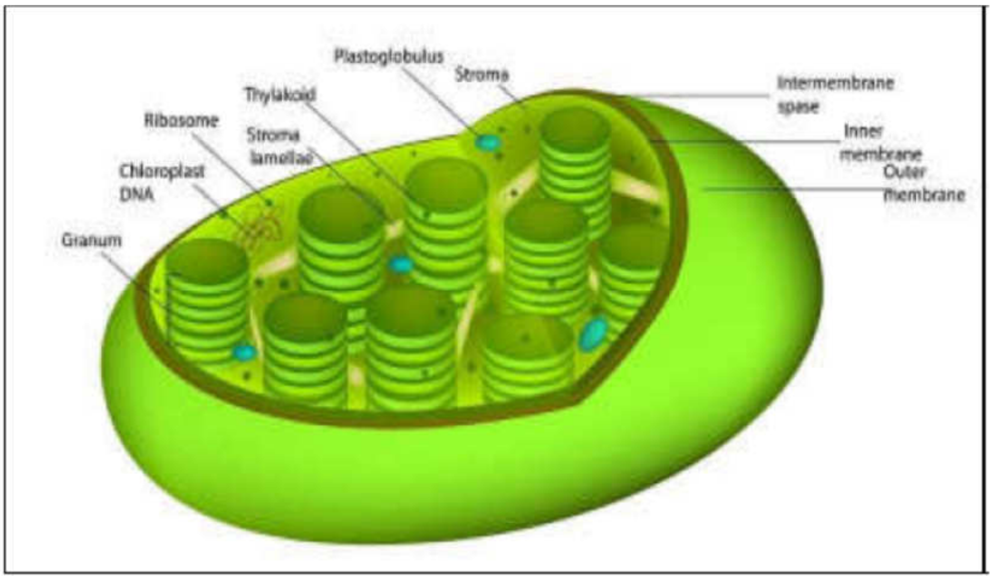


**Fig. 2.2: Labeled Diagram of a Chloroplast**

- **Vacuoles**

Plant cells are unique in that they have a large central vacuole. A vacuole is a small sphere of plasma membrane within the cell that can contain fluid, ions, and other molecules. Vacuoles are essentially just large vesicles. They can be found in the cells of many different organisms. However, plant cells characteristically have a large vacuole that can take up anywhere from 30% to as much as 90 per cent of the total cell volume. The central vacuole of a plant cell helps maintain its turgor pressure, which is the pressure of the contents of the cell pushing against the cell wall. A plant thrives best when its cells have high turgidity, and this occurs when the central vacuole is full of water. If turgor pressure in the plants decreases, the plants begin to wilt. Plant cells fare best in hypotonic solutions, where there is more water in the environment than in the cell.

Under these conditions, water rushes into the cell by osmosis, and turgidity is high.

Animal cells, in comparison, can lyse if too much water rushes in; they fare better in isotonic solutions, where the concentration of solutes in the cell and in the environment is equal and the net movement of water in and out of the cell is the same.

Many animal cells also have vacuoles, but these are much smaller and tend to play a less crucial function.

- **Cell Wall**

The cell wall is a tough layer found on the outside of the plant cell that gives it strength and also maintains high turgidity. In plants, the cell wall contains mainly cellulose, along with other molecules like hemicellulose, pectin, and lignin. The composition of the plant cell wall differentiates it from the cell walls of other organisms. For example, fungi cell walls contain chitin, and bacterial cell walls contain peptidoglycan. These substances are not found in plants. Importantly, the main difference between plant and animal cells is that plant cells have a cell wall, while animal cells do not.

Plant cells have a primary cell wall, which is a flexible layer formed on the outside of a growing plant cell. Plants can also have a secondary cell wall, a tough, thick layer formed inside the primary plant cell wall when the cell is mature.

### 3.1.3 Plant Cell Types

There are five types of **tissue** formed by plant cells, each with different **functions.** Parenchyma, collenchyma, and sclerenchyma are all simple plant tissues, meaning they contain a single cell type. In contrast, xylem and phloem contain a mixture of cell types and are referred to as complex tissues.

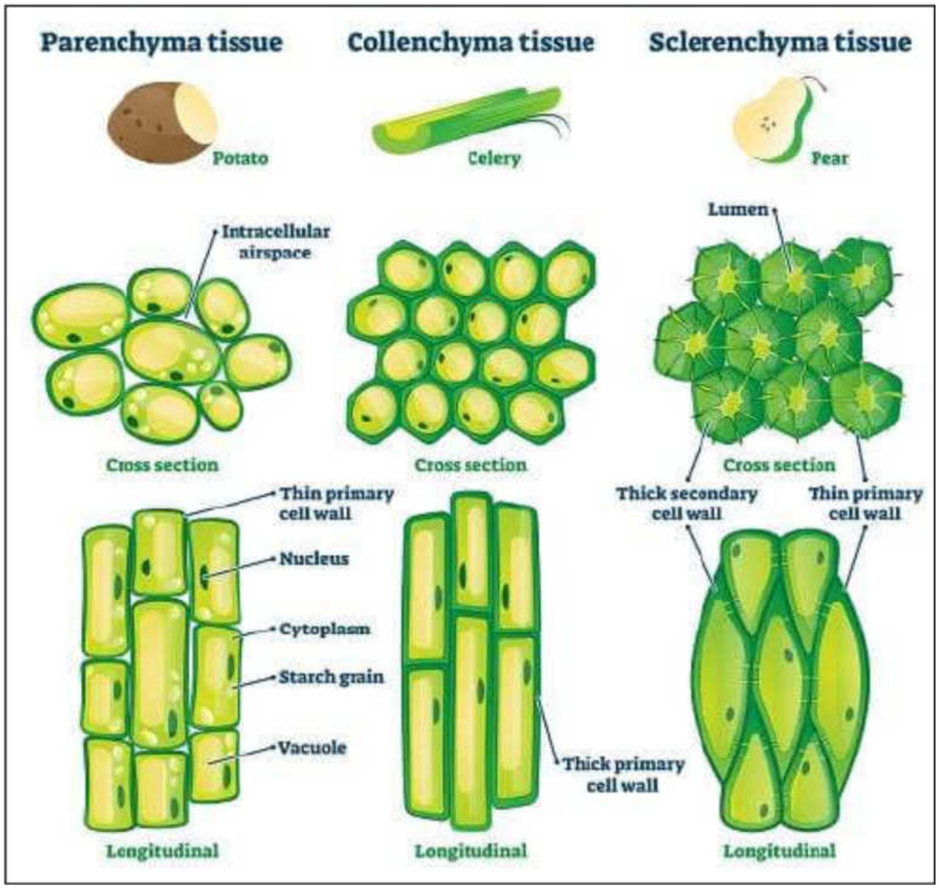


**Fig. 2.3: Plant Tissue Types Form by Parenchyma, Collenchyma and**

- **Sclerenchyma Cells**
- **Parenchyma tissue** represents the majority of cells in a plant. They are found in leaves and carry out photosynthesis and cellular respiration, along with other metabolic processes. They also store substances like starches and proteins and have a role in plant wound repair.
- **Collenchyma tissue** provides support to growing parts of a plant. They are elongated, have thick cell walls, and can grow and change shape as a plant grows.
- **Sclerenchyma tissue** contains hard cells that are the main supporting cells in the areas of a plant that have ceased growing. Sclerenchyma cells are dead and have very thick cell walls.
- **Xylem cells** transport mostly water and a few nutrients throughout a plant, from the roots to the stem and leaves.
- **Phloem cells** transport nutrients made during photosynthesis to all parts of a plant. They transport sap, which is a watery solution high in sugars.

## 4.0 SELF-ASSESSMENT EXERCISE

i. Explain the meaning of plant cell
ii. Give different definitions of plant cell
iii. Outline and explain different types of plant cell
iv. Differentiate between plant cell and animal cell

## 5.0 CONCLUSION

The cell (from Latin cellar, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole.

## 6.0 SUMMARY

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole. Plant and animal cells are both eukaryotic cells, meaning they possess a defined nucleus and membrane-bound organelles plant cells have a cell wall that surrounds the cell membrane, whereas animal cells do not. Plant cells also possess two organelles that animal cells lack: chloroplasts and a large central vacuole. These additional organelles allow plants to form an upright structure without the need for a skeleton (cell wall and central vacuole), and also allow them to produce their own food through photosynthesis (chloroplasts).

However, there are some specialized structures in plant cells, including chloroplasts, a large vacuole, and the cell wall. There are five types of tissue formed by plant cells, each with different functions**.** Parenchyma, collenchyma, and sclerenchyma are all simple plant tissues, meaning they contain a single cell type.

## 7.0 TUTOR-MARKED ASSIGNMENT

Explain the meaning of plant cell

1) Give different definitions of plant cell
2) Outline and explain different types of plant cell
3) Differentiate between plant cell and animal cell

## 8.0 REFERENCES/FURTHER READING

Biology dictionary.net Editors. “Plant Cell.” *Biology Dictionary*, Biology dictionary.net, 05 Apr. 2017, https://biologydictionary.net/plant-cell/.

## UNIT 2: BRIEF DESCRIPTION OF VARIOUS ORGANELLES AND THEIR FUNCTIONS

**CONTENTS**



## 1.0 INTRODUCTION

The cell (from Latin cellar, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. A cell is the smallest unit of life. Cells are often called the "building blocks of life". The study of cells is called cell biology. The cell was discovered by Robert Hooke in 1665, who named the biological units for their resemblance to cells inhabited by Christian monks in a monastery. Cell theory, first developed in 1839 by Matthias Jakob Schleiden and Theodor Schwann, states that

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## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Describe various organelles associated with plant
- Outline functions of the about mentioned organelles.

## 3.0 MAIN CONTENT

### 3.1 Brief Description of Various Organelles and Their Functions

The brief description of the plant cell and various organelles and their functions are as follows:

#### 3.1.1 Description of Plant Cell Wall

Cell wall is a non-living component of the cell and is secreted and maintained by the living portion of the cell, called protoplasm. A typical cell wall is composed of three different regions

i. Middle Lamella
ii. Primary cell wall (1-3 μm thick and elastic)
iii. Secondary cell wall (5-10 μm thick and rigid)

**Functions of Plant Cell Wall**

1) It protects the inner contents of the cell.

2) It gives definite shape to the cell.
3) It provides mechanical support to the tissues and act as a skeletal framework of plants.
4) It helps in transport of substances between two cells.
5) The cell wall is hydrophilic in nature and it imbibes water and helps in the movement of water and solutes towards protoplasm. It also acts as a permeable structure during absorption of minerals and solutes.

### 3.1.2 Description of Protoplasm

It is the living, colloidal and semi fluid substance. It is also called as cytoplasm. Cell devoid of cell wall is called protoplast. Protoplast is enclosed by a membrane called as cell membrane or plasma membrane.

### 3.1.3 What is a Cell membrane?

All cells are enclosed by a thin, membrane called plasma membrane or plasmalemma. The plasma membrane and sub cellular membrane are collectively called biological membrane. Cell membrane consists of proteins, lipids and other substances.

1. Proteins: - The proteins present in the membranes can be categorized into two types

a) Intrinsic proteins or integral proteins: - Which are embedded or buried in the lipid layer. These proteins associate with hydrophobic interactions to the tails or fatty acid chains of the lipid layer. In addition to the hydrophobic associations, integral proteins also possess hydrophilic amino acid residues which are exposed at the surface of the membrane. These proteins cannot be removed easily.

b) Extrinsic proteins or peripheral proteins: - They are attached to the membrane surface by weak ionic interactions. These proteins are not much involved in the architecture of membrane. Peripheral proteins are bound to hydrophilic proteins of the integral proteins protruding from the lipid layer.

2. Lipids: - The cell membrane consists of phospholipids and glycolipids. The fatty acid chains in phospholipids and glycolipids usually contain 16-20 even numbered carbon atoms. Fatty acids may be saturated or unsaturated.
3. Other substances like polysaccharide, salicylic acid etc. are found attached to the proteins or lipids on the membrane.

**Functions of cell membrane:**

1. The cell membrane surrounds the protoplasm of the cell, thus separating the intracellular components from the extracellular environment.
2. It anchors the cytoskeleton to provide shape to the cell, and in attachment to the extracellular matrix.
3. The plasma membrane is differentially permeable and able to regulate the transport across the membrane.
4. The cell membranes maintain the cell potential.

### 3.1.4 Description of Plant Cell Nucleus:

It is oval or spherical in shape and is generally larger in active cells than in resting cells. A nucleus consists of three main parts viz. nuclear envelope, nucleolus and chromatin. The nucleus is separated from the cytoplasm by a double membrane called the nuclear envelope. The space between the outer and inner membrane is known as nuclear pores which provide direct connection between nucleus and cytoplasm. Nucleolus is a spherical, colloidal body found in the nucleus and is the place where almost all DNA replication and RNA synthesis occur. Chromatin is the basic unit of chromosome and contains genes which play important role in the inheritance of characters to offspring from parents.

Functions of plant cell nucleus:

1. It regulates growth and reproduction of cells.
2. The nuclear envelope allows the nucleus to control its contents, and separate them from the rest of the cytoplasm where necessary.
3. The DNA replication, transcription and post transcriptional modification occur in the nucleus.

### 3.1.5 Description of Chloroplast

Chloroplasts are organelles found in plant cells and other eukaryotic organisms that perform photosynthesis because of the presence of green pigment, chlorophyll. They are flattened discs usually 2-10 micrometers in diameter and 1 micrometer thick. The chloroplast is surrounded by double layered membrane. The space between these two layers is called intermembrane space. Stroma is the aqueous fluid found inside the chloroplast. The stroma contains the machinery required for carbon fixation, circular DNA, 70 S ribosomes (that why called as semiautonomous organelle) etc. within the stroma the stacks of thylakoids are arranged as stacks called grana. A thylakoid has a flattened disc shape and has a lumen or thylakoid space. The light reactions occur on the thylakoid membrane.

**Functions of chloroplast:**

1. The important processes of photosynthesis i.e., light and dark reactions occur within the chloroplast.
2. The granum is the site of NADP reduction forming NADPH+H+ and photophosphorylation i.e., formation of ATP in presence of light. Thus, light reaction of photosynthesis takes place in the granum region.
3. The stroma is the main site for the dark reaction of photosynthesis.
4. The chloroplast has its own genetic system and is self replicating, thus, associated with cytoplasmic inheritance.

### 3.1.6 Description of Mitochondria:

Mitochondria are rod shaped cytoplasmic organelles, which are main sites of cellular respiration. Hence, they are referred to as power house of the cell. Each mitochondrion is enclosed by two concentric unit membranes comprising of an outer membrane and an inner membrane. The space between the two membranes is called peri mitochondrial space. The inner membrane has a series of infoldings known as cristae. The inner space enclosed by cristae is filled by a relatively dense material known as matrix. The matrix is generally homogeneous but may rarely show finely filamentous or fibrous structures. The matrix contains several copies of round or circular DNA molecules and 70 S ribosomes (that why it is also called as semiautonomous organelle).

**Functions of mitochondria**:

1. ATP, the readily available form of energy is produced in mitochondria.
2. Krebs cycle takes place in the matrix of mitochondria.
3. The enzymes of electron transport chain are found in the inner membrane or cristae of mitochondria.
4. Heme synthesis occurs in mitochondria.
5. Controls the cytoplasmic $Ca^{2+}$ concentration

### 3.1.7 Description of Ribosomes:

Chemically, ribosomes are ribonucleoprotein complexes. This is a membrane less Ribosomes are of two types. Ribosomes of prokaryotes have sedimentation coefficient of 70 S and consist of two sub units of unequal sizes 50S and 30 S subunits. Ribosomes of eukaryotes have 80 S sedimentation coefficient (40S & 60 S). The two or more ribosomes become connected by a single m RNA and then may be called polyribosome. The major function of the smaller subunit of ribosome is to provide proper site for binding of mRNA and its translation. The larger subunit of ribosome supports translation and translocation processes coupled with polypeptide synthesis.

**Functions of Ribosomes:**

1. They provide the platform for protein synthesis
2. They have the machinery for protein synthesis.

### 3.1.8 Description of Golgi Complex

Golgi bodies is an assemblage of flat lying cisternae one above the other in close parallel array. Each Golgi complex has 3 to 12 interconnected cisternae which are composed of lipoproteins.

**Functions of Golgi complex:**

1. It helps in Packaging of proteins for exporting them.
2. It plays a role in sorting of proteins for incorporation into organelles. 3. It is involved in the formation of the cell wall of plant cells.

### 3.1.9 Meaning of Endoplasmic Reticulum:

Endoplasmic reticulum arises from the outer membrane of the nucleus forming an intermediate meshed network. It is of two types, the granular or rough endoplasmic reticulum in which the outer surface of endoplasmic reticulum is studded with ribosome and agranular or smooth endoplasmic reticulum in which the ribosomes are not attached.

**Functions of Endoplasmic reticulum:**

1. Rough endoplasmic reticulum is associated with the synthesis of proteins.
2. Smooth endoplasmic reticulum is associated with synthesis of lipids and glycogen.
3. It acts as an inter-cellular transport system for various substances.
4. It contains many enzymes which perform various synthetic and metabolic activities.

### 3.1.10 Meaning of Vacuole:

It is a membrane bound organelle found in plant cell and occupies most of the area in the plant cell. A vacuole is surrounded by a single layer membrane called tonoplast. It is an enclosed compartment filled with water containing inorganic and organic molecules including enzymes in solution. It maintains the cell's turgor, controls movement of molecules between the cytosol and sap, stores useful material and digests waste proteins and organelles.

**Functions of vacuole:**

1. Isolating materials that might be harmful or a threat to the cell.
2. Stores waste products.
3. Maintains internal hydrostatic pressure or turgor within the cell.
4. Maintains an acidic internal pH.
5. Exports unwanted substances from the cell.
6. Allows plants to support structures such as leaves and flowers due to the pressure of the central vacuole.
7. Most plants store chemicals in the vacuole that react with chemicals in the cytosol.
8. In seeds, stored proteins needed for germination are kept in protein bodies which are modified vacuole.

### 3.1.11 Description of Micro bodies

Micro bodies are ubiquitous organelles found in the majority of eukaryotic plant cells. They are mostly spherical and have a diameter ranging from 0.2um to 1.5um. Two types of micro bodies, peroxisomes and glyoxysomes, have been characterised. These organelles differ in their distribution and enzyme composition, although both have the capacity to transform non-carbohydrate material into carbohydrate.

### 3.1.12 Meaning of Peroxisomes:

Peroxisomes are found in leaves of higher plants. It is a small organelle present in the cytoplasm of many cells, which contains the reducing enzyme catalase and usually some oxidases.

**Functions of Peroxisomes:** Peroxisomes act in parallel with chloroplast in higher plants and are believed to undertake photorespiration.

### 3.1.13 Meaning of Glyoxysomes:

A glyoxysome is a specialised form of peroxisome (a type of microbody) found in some plant cells, notably the cells of germinating seeds. Glyoxysomes are temporary as they occur during transient periods in the life cycle of a plant such as in certain beans and nuts which store fats in their seeds as energy reserves.

Glyoxysomes appear in the first few days after seed germination in endosperm cells and associate closely with lipid bodies. They disappear after the storage fats are broken down and converted into carbohydrate.
**Functions of Glyoxysomes:** Glyoxysomes are involved in the formation of sugars by the breakdown of fatty acids in germinating seeds.

### 3.1.14 Description of Cytoskeleton

The cytoskeleton is scaffolding contained within the cytoplasm and is made up of protein. The cytoskeleton is present in all cells. The cytoskeleton provides the cell with structure and shape

There are three main kinds of cytoskeleton filaments:

1. Microfilament: - They are composed of actin subunits.
2. Intermediary filaments: - They function in the maintenance of cell shape by bearing tension. They also participate in the cell and cell matrix junctions.
3. Microtubules: - They are like hollow cylinders mostly comprising of 13 protofilaments which in turn are alpha and beta tubulin. They are commonly organised by the centrosome.

**Functions of cytoskeleton**

1. Provides mechanical support
2. Anchors organelles
3. Helps to move substances intracellular.

### 3.1.15 Description of Plasmodesmata:

Plasmodesmata (singular: plasmodesma) are microscopic channels which traverse the cell walls of plant cells and some algal cells, enabling transport and communication between them. Specialised cell-to-cell communication pathways known as plasmodesmata, pores in the primary cell wall through which the plasmalemma and endoplasmic reticulum of adjacent cells are continuous. Unlike animal cells, almost every plant cell is surrounded by a polysaccharide cell wall. Neighbouring plant cells are therefore separated by a pair of cell walls and the intervening middle lamella, forming an extracellular domain known as the apoplast. Although cell walls are permeable to small soluble proteins and other solutes, plasmodesmata enable direct, regulated, symplastic transport of substances between cells. There are two forms of plasmodesmata: primary plasmodesmata, which are formed during cell division, and secondary plasmodesmata, which can form between mature cells.

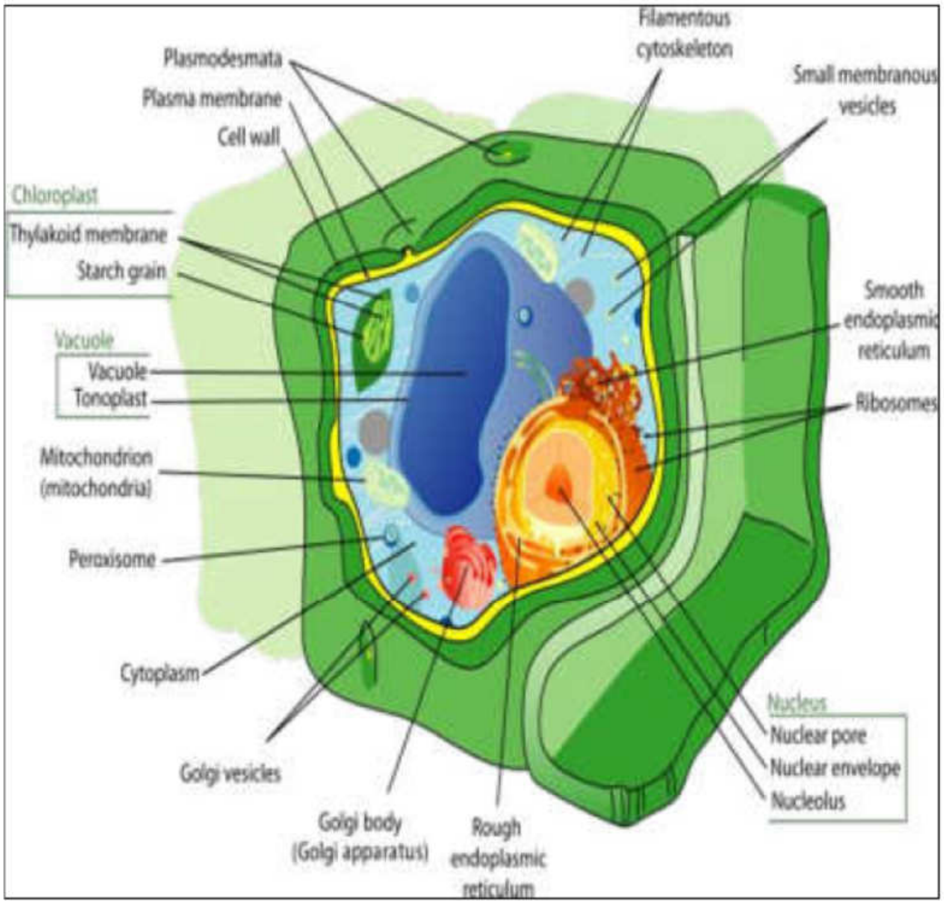


**Fig.2.4: Diagrammatic Representation of Typical Plant Cell**

## 4.0 SELF-ASSESSTMENT EXERCISE (SAE)

1. Describe various organelles associated with plant
2. Outline functions of the about mentioned organelles.

## 5.0 CONCLUSION

In this unit, the brief description of various organelles and their functions were brought forth.

## 6.0 SUMMARY

The descriptions and functions were done various organelles such as Plant Cell Wall, Cell membrane, Cell Nucleus, Chloroplast, Mitochondria, Ribosomes, Golgi complex, Endoplasmic reticulum, Vacuole, Microbodies: Peroxisomes and Glyoxysomes, Cytoskeleton and Plasmodesmata

## 7.0 TUTOR-MARKED ASSIGNMENT

Give Descriptions and functions of any five of the following;

- Plant Cell Wall,
- Cell membrane,
- Cell Nucleus,
- Chloroplast,
- Mitochondria,
- Ribosomes,
- Golgi complex,
- Endoplasmic reticulum,
- Vacuole,
- Microbodies: Peroxisomes and Glyoxysomes,
- Cytoskeleton and
- Plasmodesmata

## 8.0 REFERENCES/FURTHER READING

Biologydictionary.net Editors. "Plant Cell." *Biology Dictionary*, Biologydictionary.net, 05 Apr. 2017, https://biologydictionary.net/plantcell/

## MODULE 3: CROP PHYSIOLOGY AND ITS IMPORTANCE IN AGRICULTURE



## UNIT 1: A BRIEF HISTORY OF CROP PHYSIOLOGY

**CONTENTS**



### 1.0 INTRODUCTION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture. The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8).

Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

## 2.0 Objectives

By the end of this unit, you should be able to:

- Give a brief history of evolution of crop physiology through various stages.

## 3.0 MAIN CONTENT

### 3.1 Brief History of Crop Physiology

#### 3.1.1 Early Experiments on Growth

An early physiological question was where a plant gets the material with which it grows. In the early 1600s, Jan van Helmont, a Belgian physician, decided the source must be water alone. Van Helmont grew a willow seedling in 200 pounds of soil, and only added rainwater. A 164- pound tree was produced with only 57.1 grams (2 ounces) of soil lost. He knew of carbon dioxide but never dreamed that a diffuse gas could produce willow wood.

In the next century Antoine Lavoisier found organic matter to be largely formed of carbon and oxygen. Joseph Priestley, Jan Ingenhousz, and Jean Senebier demonstrated that plant leaves in light take up carbon dioxide and emit equivalent amounts of oxygen. Later, Nicholas de Saussure noted that water was involved in the process. The reverse occurred in the dark—plants respired like animals, taking up oxygen and emitting carbon dioxide. J. R. Mayer observed that the process converted light energy into the chemical energy of organic carbon. Thus, growth of seedlings in the dark or of roots in the soil was at the expense of this energy. Therefore, by the nineteenth century, photosynthesis, although not understood biochemically, was established as the primary and essential synthetic process in plant growth.

#### 3.1.2 Experiments on Plant Nutrition and Transportation

In his experiment, van Helmont assigned no importance to the two ounces of soil lost. However, starting in the late 1700s and extending into the mid-1800s, Julius Sachs and others used chemical assays to establish that quantitatively minor soil constituents of nitrogen, potassium, phosphate, sulphur, and other elements had major importance in plant growth. The long-recognised importance of manure lay with its content of these inorganic nutrients, especially nitrogen. It was discovered these could be added to the soil as inorganic salts, such as potassium nitrate. The organic material of manure, or the residue of its decay, contributed to improved tilth, or soil structure, but did not provide nutrients. From these discoveries came the modern agricultural use of chemical fertilizers.

What about the extensive loss of water from the soil? Van Helmont had to continuously water his willow tree with many more pounds of water than were ultimately incorporated by the tree. In 1727 an English clergyman and amateur physiologist, Stephen Hales, published *Vegetable Staticks,* an account of his pioneering studies on the transpiration, growth, and gas exchanges of plants. Hales demonstrated that water from the soil moves up the stems to the leaves where it is lost as water vapour, a process called transpiration. Subsequent research of the 19th and early 20th centuries showed that the water diffuses out through stomata (singular stoma), pores in the leaf epidermis (outer layer of leaf cells).

With light and adequate water, the two cells bounding the stoma inflate, opening the pore to gas diffusion; under dry conditions the cells grow flaccid and the pore closes, conserving water. Capillary forces originating in the microscopic pores of the leaf mesophyll (internal green photosynthetic cells), with some contribution from osmosis, pull columns of water up the open vessels and tracheid of the xylem (wood) carrying nutrient salts from the roots. The coherence between water molecules and their adherence to cell walls prevents the taut water columns from breaking even in trees of great height. This scheme was first proposed in 1895 by Henry Dixen and John Joly. Numerous researchers in the 20th century confirmed and refined this "cohesion-tension" theory of transportation.

Hales also measured the root pressure (forced bleeding) of decapitated plants. Subsequent work showed that under conditions of good soil moisture and aeration, roots actively secrete high concentrations of salt into the root xylem creating a high osmotic pressure that forces water up the stem and out pores at the tips of leaves (guttation). In 1926, E. Munch proposed a similar mechanism for translocation, the movement of sugars from leaves to roots and other plant parts. This mechanism is known as the pressure flow model. In 1915 Crop physiology, with the aim of understanding the dynamics of yield development in crops, really began with the work of W.L. Balls. Along with Holton he analysed the effects of plant spacing and sowing date on the development and yield of Egyptian cotton plants within crop stands, not in isolated plants. It was from his work the term 'crop physiology' came into existence. From then onwards, various scientists have started applying the advances in physiological knowledge for better crop management. In 1924, in England- a rapid development of the methods of growth and yield analysis by different investigators (V.H. Blackman, F.G. Gregory, G.E. Briggs etc.) was started. With the development of various methods of growth analysis, they started explaining 'the physiology of crop yield' in 1947, the concept of LAI (Leaf area index) was developed by D.J. Watson. This index has provided a more meaningful way of analysing growth in crops, and stimulated renewed interest in crop physiology. In 1950's, studies on photosynthetic rate of the leaf and the loss of photosynthates by respiration was studied by the development of 'Infra-Red Gas Analysis (IRGA)'method. This method has facilitated the estimation of short-term rates of Photosynthesis and respiration by crops in the field. In 1953, Monsi and Saeki explained about the manner of light interception by the crop canopy with their concept of light interception coefficient.

In 1963, Hesketh and Moss showed that photosynthesis by leaves of Maize, Sugarcane and related tropical grasses could reach much higher rates, with less marked light saturation, than leaves of other plants. (This was the starting point for research to find other photosynthetic $CO_2$ fixation path ways like $C_4$, and CAM Mechanisms). The differences in pathway are associated with differences in photosynthetic rate, in response to light intensity, temperature and oxygen level, in photorespiration, in leaf anatomy and chloroplast morphology, in rate of translocation, and in the efficiency of water use, which can have profound effects on the physiology of yield determination.

### 3.1.3 Current Research on Cellular and Molecular Plant Physiology

By the 20th century, plant physiologists increasingly turned to chemistry and physics for assistance with fundamental questions. They also established their own societies with journals to publish their findings, which had a catalytic effect in increasing the level and amount of research. A great deal of the fundamental biochemistry of cell growth and function, known from the more extensive medical, animal, and microbiological research, was found to apply to plant cells. Anatomical studies gave

structural details to support physiological findings, and sub microscopic cell structure was revealed by the electron microscope.
All the mineral nutrients required for plant growth were established. The key to their selective uptake from the soil and transport into the root xylem proved to lie with an energy-requiring proton (hydrogen ion**)** pumping mechanism in the cell membranes.

Environmental, hormonal, and genetic controls on growth and development have been extensively explored, but there is still more to learn. Ethylene, a simple two-carbon gas generated by plants initiates fruit ripening and regulates aspects of seed germination. Phototropism's (bending in response to unilateral light, investigated by Charles Darwin), and geotropisms (root growth down, stem growth up) were found to be due to displacement of a cell growth hormone, or auxin. In some circumstances, auxins could also elicit cell division (root formation in stem cuttings). Other hormones, the gibberellins, regulate cell division at the stem apex and activate enzyme formation in seed germination.

Attempts to culture plant tissues led to discovery of more cell division hormones, the cytokinin. Another type of hormone, abscisic acid, initiates the senescence and abscission of leaves in the fall, and causes the stomata to close under water stress. Additional growth regulating compounds are being found and investigated but a coordinated picture of hormone interaction is lacking.

Photoperiodism, the regulation of flowering by day length was discovered. Sleep movements, such as the drooping of bean leaves in the evening, were found to be controlled by a biological "clock," a circadian rhythm, not by the onset of darkness. In 1952, phytochrome was discovered and found to be the pigment at the center of photoperiodism.
In recent years there has been a major shift to molecular genetics in attempts to locate the genes responsible for physiological processes. In photosynthesis chlorophyll structure was determined and localised in the internal membranes of the chloroplasts of the mesophyll cells. Red and blue portions of the light spectrum were found effective, leading to the discovery that two light reactions are required. In the 1930s, C. B. Van Neil used radioactive water to show that water, not carbon dioxide, was the source of oxygen released during photosynthesis. Sugar was found to be synthesised in the stroma (fluid part) of the chloroplast, and the molecular details of its creation were worked out by Melvin Calvin and

Andrew Benson. All plant cells were found to respire, an energy yielding process essentially the same as that in animals, involving another membranous organelle, the mitochondrion, and yielding metabolic energy available for transport reactions and synthesis of cellsubstance.

The formation of fats and oils from carbohydrates was found to be similar to that in animals, but plants had the added ability to transform oils in germinating seeds into carbohydrates such as the glucose used in cellulose wall formation. The symbiotic relationships of plants and microorganisms were explored, notably in the cases of reduced nitrogen formation from atmospheric nitrogen by nodule bacteria.

At the end of 20th century, the small mustard plant Arabidopsis thaliana took center stage in the attempt of scientists to understand plant genomes. The full sequence of this genome was elucidated in 200 by an international consortium of plant geneticists. Later on, several research works were carried out to understand the processes like translocation of food materials, their partitioning towards economic yield, storage mechanisms, physiology of flowering, effect of stressful environmental factors on crop growth and development, role of plant growth regulators in increasing the crop productivity etc. All these areas have enriched the knowledge of physiological processes and their role in deciding the crop yield.

## 4.0 SELF-ASSESSMENT EXERCISE

- Attempt to differentiate the history of crop physiology based on different stages of researches with dates.

## 5.0 CONCLUSION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture.

The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8).

Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

## 6.0 SUMMARY

A brief history of Crop Physiology based on Early Experiments on Plant Growth, Experiments on Plant Nutrition and Transportation and Current Research on Cellular and Molecular Plant Physiology were discussed in this unit. Some of the discoveries by different researchers at different times were as follows;

- An early physiological question was where a plant gets the material with which it grows. In the early 1600s, Jan van Helmont, a Belgian physician, decided the source must be water alone. Van Helmont grew a willow seedling in 200 pounds of soil, and only added rainwater. A 164-pound tree was produced with only 57.1 grams (2 ounces) of soil lost. He knew of carbon dioxide but never dreamed that a diffuse gas could produce willow wood.
- Van Helmont assigned no importance to the two ounces of soil lost. However, starting in the late 1700s and extending into the mid-1800s, Julius Sachs and others used chemical assays to establish that quantitatively minor soil constituents of nitrogen, potassium, phosphate, sulphur, and other elements had major importance in plant growth.
- Crop physiology, with the aim of understanding the dynamics of yield development in crops, really began with the work of Balls (1915). Along with Holton he analysed the effects of plant spacing and sowing date on the development and yield of Egyptian cotton plants within crop stands, not in isolated plants. It was from his work the term ‘crop physiology’ came into existence. From then onwards, various scientists have started applying the advances in physiological knowledge for better crop management.
- In 1924, in England- a rapid development of the methods of growth and yield analysis by different investigators (V.H. Blackman, F.G. Gregory, G.E. Briggs etc.) was started. With the development of various methods of growth analysis, they started explaining ‘the physiology of crop yield’
- In 1947, the concept of LAI (Leaf area index) was developed by D.J. Watson. This index has provided a more meaningful way of

analysing growth in crops, and stimulated renewed interest in crop physiology.

- In 1950's, studies on photosynthetic rate of the leaf and the loss of photosynthates by respiration was studied by the development of 'Infra-Red Gas Analysis (IRGA)'method. This method has facilitated the estimation of short-term rates of Photosynthesis and respiration by crops in the field. Monsi and Saeki explained about the manner of light interception by the crop canopy with their concept of light interception coefficient.
- In 1963, Hesketh and Moss showed that photosynthesis by leaves of Maize, Sugarcane and related tropical grasses could reach much higher rates, with less marked light saturation, than leaves of other plants. (This was the starting point for research to find other photosynthetic $CO_2$ fixation path ways like $C_4$, and CAM Mechanisms). The differences in pathway are associated with differences in photosynthetic rate, in response to light intensity, temperature and oxygen level, in photorespiration, in leaf anatomy and chloroplast morphology, in rate of translocation, and in the efficiency of water use, which can have profound effects on the physiology of yield determination.
- By the 20th century, plant physiologists increasingly turned to chemistry and physics for assistance with fundamental questions. They also established their own societies with journals to publish their findings, which had a catalytic effect in increasing the level and amount of research.

## 7.0 TUTOR-MARKED ASSIGNMENT

Briefly discuss the history of Crop Physiology base on the following headings;

a) Early Experiments on Plant Growth
b) Experiments on Plant Nutrition and Transportation
c) Current Research on Cellular and Molecular Plant Physiology

## 8.0 REFERENCES/FURTHER READING

Dennis, D. T. & Turpin D. H. (1990). *Plant Physiology, Biochemistry and Molecular Biology*. Harlow, Essex, UK: Longman Group.

Salisbury, F. B. & Ross, C. W. (1985). *Plant Physiology*, (3rd ed.). Belmont, CA: Wadsworth Publishing.

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## UNIT 2: MEANING OF CROP PHYSIOLOGY AND ITS IMPORTANCE IN AGRICULTURE

**CONTENTS**



### 1.0 INTRODUCTION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture.

The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8). Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

Many aspects of Agriculture and Horticulture can be benefitted from more intensive research in plant physiology to provide practical solutions in agriculture and horticulture. Understanding the physiological aspects of seed germination, seedling growth, crop establishment, vegetative development, flowering, fruit and seed setting and crop maturity, plant hormone interaction, nutrient physiology, stress (biotic/abiotic) physiology etc., provides a reasonable scientific base for effective monitoring and beneficial manipulation of these phenomena. Since in agriculture we are interested in economic yield which is the output of these phenomenons and well-being of plants, Plant Physiology provides a platform for getting better yield of crops. Studying these phenomena with a view to develop better crop management practices forms the subject matter of crop physiology.

Crop physiology is important in agriculture as well as horticultural crops because:

- It studies the entire plant and its communities.
- They deal with a plant in terms of knowledge from the different field such as soil science, plant physiology, botany etc.
- It aims to "increase the yield" of the plant economically."

## 2.0 OBJECTIVES

By the end of this unit, you should be able to**:**

- Explain the meaning of crop physiology
- Outline the importance of crop physiology in agriculture

## 3.0 MAIN CONTENT

### 3.1 Meaning of Crop Physiology

Crop physiology is the study of the ways in which plant physiological processes are integrated to cause whole plant responses in communities. The subject matter of crop physiology includes the ways in which the knowledge of plant physiology is applied for better management of crops. Crop physiology is the study of the plant processes responsible for the growth, development, and production of economic yield by crop plants.
Crop physiologists focus on whole plants and plant communities – not individual plant parts, organs, or cells because most of the processes that control yield operate at the whole plant - plant community level. Consequently, most crop physiology research is conducted in growth chambers, greenhouses, or in the field. Crop physiologists investigate processes responsible for the primary productivity of crop communities (e.g., photosynthesis, respiration, light interception, nutrient utilisation), how the products of these processes are converted to economic yield (e.g., sink size, seed growth, partitioning, senescence), and developmental

processes that define the length of critical growth stages by controlling flowering and maturation. Crop physiology is an integrative science, bringing information from a variety of disciplines (soil science, ecology, plant physiology, botany, statistics, micro meteorology, modeling) to bear on problems of yield improvement and crop management.

Crop physiology has an important role to play in generating the large increases in yield that will be needed in the next 20 years to feed a burgeoning world population. Increasing total production in a sustainable manner without increasing the land area under cultivation represents a huge challenge that can only be met by integrative investigations at the whole plant-plant community level. Crop physiologists will make significant contributions to meeting this challenge.

## 3.2 Importance of Crop Physiology in Agriculture

Many aspects of Agriculture and Horticulture can be benefitted from more intensive research in plant physiology to provide practical solutions in agriculture and horticulture. Understanding the physiological aspects of seed germination, seedling growth, crop establishment, vegetative development, flowering, fruit and seed setting and crop maturity, plant hormone interaction, nutrient physiology, stress (biotic/abiotic) physiology etc., provides a reasonable scientific base for effective monitoring and beneficial manipulation of these phenomena. Since in agriculture we are interested in economic yield which is the output of these phenomenon and well-being of plants, Plant Physiology provides a platform for getting better yield of crops. Studying these phenomena with a view to develop better crop management practices forms the subject matter of crop physiology.

The importance of physiology in agriculture and horticulture can be seen from the following examples;

1. **Seed Physiology**

Seed is the most important input in agriculture. Germination of seed and proper establishment of seedling depends upon various internal and external factors. Knowledge of Seed physiology helps in understanding of different physiological and morphological changes that occur during germination. Any deviation in these processes causes Seed dormancy. The dormant condition of the seed bars immediate use of harvested seed for next crop which is important in intensive agriculture. By understanding the causes and effects of this problem, Crop physiologists have come up with different methods of breaking the seed dormancy. Example: Whenever Paddy is used as a seed material in the very next season it is recommended to treat the seed either with $HNO_3$ or with GA.

2. **Optimum seedling growth and plant population**

By knowing the process of radicle and plumule emergence and their function we can achieve best plant health, which is the outcome of best plant physiology. By knowing the different inputs requirement of plants (water, nutrients, sunlight) we can easily manage the plant populations to get highest yield. Input interaction of plants within their body is the matter of plant physiology.

3. **Growth measurement of crops**

The first prerequisite for higher yields in crops is high total dry matter production per unit area. High dry matter production is a function of optimum leaf area (Optimum leaf area Index) and Net Assimilation rate. (CGR = LAI X NAR).

Example: Pruning operation in horticultural crops like mango is done based on this principle of proper canopy management for better photosynthesis.

4. **Harvest index**

The difference between total amount of dry matter produced and the photosynthates used in respiration is the net product of photosynthesis. Economic yield depends on how the dry matter is distributed among different organs of the plant. Partition of total dry matter amongst the major plant organs is of interest to the farmers as they are more interested in its partition towards economic yield.

Example: excessive vegetative growth period in Ground nut produces a smaller number of Pods as the reproductive period gets constricted. Thus, groundnut varieties with relatively extended period of reproductive growth are desirable.

5. **Mode of action of different weedicides**

The use of herbicides to kill unwanted plants is widespread in modern agriculture. Majority of Herbicides -about half of the commercially important compounds—act by interrupting photosynthetic electron flow (Ex. Paraquat, diuron) or electron flow of respiration. In Photosynthesis when the electron transport is blocked, it virtually stops light reaction of photosynthesis. When light reaction is stopped the dark reaction does not happen and thus $CO_2$ is not fixed as carbohydrate. Therefore, the weed is killed by starvation.

6. **Nutriophysiology**

Nutriophysiology is yet another important area to understand crop physiology. For the healthy growth of a crop around 17 essential elements are required. Knowledge of nutriophysiology has helped in identification of essential nutrients, ion uptake mechanisms, their deficiency symptoms and corrective measures. It also helps to check the toxicity symptoms of various nutrients. The use of fertilizers and their intake by plants can be totally understood by studying plant physiology.

7. **Photoperiodism**

Response of plant to the relative length of day and night is called as photoperiodism. This concept was used to choose photo insensitive varieties. The semi dwarf Rice varieties that have revolutionized Indian agriculture, are lodging resistant, fertilizer responsive, high yielding and photo insensitive. Photo insensitivity has allowed rice cultivation in nontraditional areas like Punjab. Even in traditional areas rice-wheat rotation has become possible only due to these varieties.

8. **Plant growth regulators**

Plants can regulate their growth through internal growth mechanisms involving the action of extremely low concentrations of chemical substances called Plant growth substances, phytohormones or Plant growth regulators. The regulation of flowering, seed formation and fruit setting has been controlled through the application of different hormones at the appropriate time of plant height and age.

Indian agriculture being predominantly rain fed in nature, so development of drought resistant varieties is very important. Root zone depth, density of roots, plant water potential, relative water content, water use efficiency, xerophytic characters of leaves etc. are some of the characters helped to breed drought tolerant varieties and to develop efficient irrigation management practices (sprinkler and drip irrigation).

Among Several physiological approaches, transpiration efficiency or water use efficiency is the most dependable trait, which is “the amount of dry matter produced per unit amount of water transpired”. The importance of water use efficiency (WUE) in influencing grain yield under water limited conditions can be explained by the following model given by passioura.

Grain Yield = T x TE x HI

Where T = Total transpiration by the crop canopy

TE = Transpiration

Efficiency or WUE

HI = Harvest Index (Economic Fraction of Dry matter)

This relationship provides an analytical tool to select the genotype with high levels of T and TE.

9. **Post-harvest physiology**

Post-harvest losses of agriculture and horticulture are causing a great distress to farming community. Moisture and temperature are the two important factors causing physiological changes that reduce the postharvest quality of grains. Control of moisture content and maintenance of low temperatures have proved effective in storage of grains. Being perishable in nature the magnitude of post-harvest loss is comparatively higher in horticultural crops. Example: In recent years a method called 'modified atmospheric storage' was developed for prolonged post-harvest life of fruits and vegetables. Shelf life of cut flowers can be increased by application of kinetin (cytokinin).

This will reduce the burst of ethylene and thus reduces the rate of senescence. Thus, physiological understanding of crop plants provides the fundamental scientific base about various aspects of metabolism, growth and development. This is immensely important for crop improvement or technology improvement in agriculture or horticulture.

## 4.0 SELF-ASSESTMENT EXERCISE

- What is the meaning of crop physiology?
- Outline the importance of crop physiology in Agriculture as it's relates to Nigerian Context.

## 5.0 CONCLUSION

The study of plant physiology is important in agriculture. It is the science and art of how plants are cultivated. Agriculture is the base of the development of human civilization. The works related to farming of domesticated species generate food surpluses which make people able to live in cities. The modern agriculture deals with plant breeding, agronomy and agrochemicals such as the use of the fertilizers and the pesticides. The technological developments have changed the conventional agricultural processes significantly. The technological developments have increased the number of crops. Along with it, the technological tools caused environmental and economic changes.

The modern agricultural practices are also shaped by depletion of aquifers, global warming, deforestation, use of growth hormones and antibiotics. Increase demand for genetically modified organisms is another key trend in agriculture. The products in the agricultural industry are broadly categorized as fibres, foods, raw materials and fuels. The food products obtained from the agricultural industry are classified as vegetables, cereals, oil and fruit.

The applied researches, on the contrary, give importance to solving practical problems. However, the crop physiology studies the plants and plant communities as a whole. This is because the processes which control the production. The area also gives importance to studying how the plants interact with the environment.

## 6.0 SUMMARY

In this unit, it has been established that crop physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture. The knowledge of the physiological factors associated with the plants is essential for conducting the agricultural works effectively. Crop physiology is an important part of the subject. It deals with investigating different processes in the plants. The key areas of focus in the domain of Crop physiology are — the activities which drive growth in the plants, the development processes and the, production of crop plants in an economic manner.

This area of the subject includes both the basic and applied research to determine the functionalities of the crop plants. The basic researches in the crop physiology give importance to developing knowledge in the area.

## 7.0 TUTOR-MARKED ASSIGNMENT

Briefly discuss Crop Physiology base on the following headings;

a) Meanings
b) Importance and
c) Current research and molecular plant physiology

## 8.0 REFERENCES/FURTHER READING

Dennis, D. T. & Turpin, D. H. (1990). *Plant Physiology, Biochemistry and Molecular Biology*. Harlow, Essex, UK: Longman Group.

Salisbury, F. B. & Ross, C. W. (1985). *Plant Physiology*, 3rd ed. Belmont, CA: Wadsworth Publishing.

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http://www.biologyreference.com/Gr-Hi/History-of-Plant-Physiology.html#ixzz6fwOQSNmG.

## UNIT 3: PHYSIOLOGY OF FLOWERING

## CONTENTS



## 1.0 INTRODUCTION

After attaining certain growth the plants begin to flower. Flower is reproductive organ of plants and most of the plants utilize the process of flowering as a mode of reproduction. Flowering is followed by pollination, fertilization which ultimately leads to formation of fruits/seeds. The time taken by a plant to flower varies from species to species. For example so many fruiting trees which you commonly see around such as mango tree, guava tree etc take many years before they begin to flower and fruit. Many herbs begin to flower in few months. Such plants have very short vegetative phase and the reproductive phase (flowering) begins early. Different plant species may exhibit different pattern of growth before they begin to flower, for example corn plants does not begin to flower until they have produced certain number of leaves. Plant of bamboo takes several years (more than 30 or 50 years depending upon species) to flower. Flowering in plants crucially depends upon season. Each plant displays a strict and definite pattern of their vegetative and reproductive growth depending upon season. It means that every plant require specific seasonal/ environmental condition before they begin to flower. In this chapter you will come to know how seasons, length of day and night control flowering in plants.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Understand the Physiological mechanism for flowering in plant
- Effect of photoperiod on flowering in plants
- Effect of quality of light and phytochrome on flowering
- Role of temperature in regulating flowering
- Practical utilization / application of photoperiodism and vernalization

## 3.0 MAIN CONTENTS

### 3.1 Basic Concept of Flowering

After attaining certain vegetative growth, plants undergo structural and functional changes and reproductive growth begins leading to flowering. Flowering in plants is influenced by various experimental factors. Plant will respond to environmental factors (for flowering) only when the plant has reached certain stage of maturity. It means that if a plant is provided with all the favourable conditions required for flowering but if the plant is not mature enough it will not flower. Flowering crucially depends upon developmental status of plants among different environmental factors, length of days, quality and intensity of light and temperature are among the most important factors which control flowering in plants.

After sufficient amount of vegetative growth, if plant is provided with suitable environmental conditions, the development of plant shifts towards reproductive growth. Several changes occur at metabolic level including changes in kind and amount of hormones produces, production of metabolites required for reproductive growth, etc. Stimulus for flowering is perceived by leaves (discussed in detail later in the chapter), the flowering stimulus from leaves in form of hormones is transferred from leaves to shoot tips / nodes. Formation of floral buds occurs at shot tips which ultimately results in flowering (Fig.3.1).

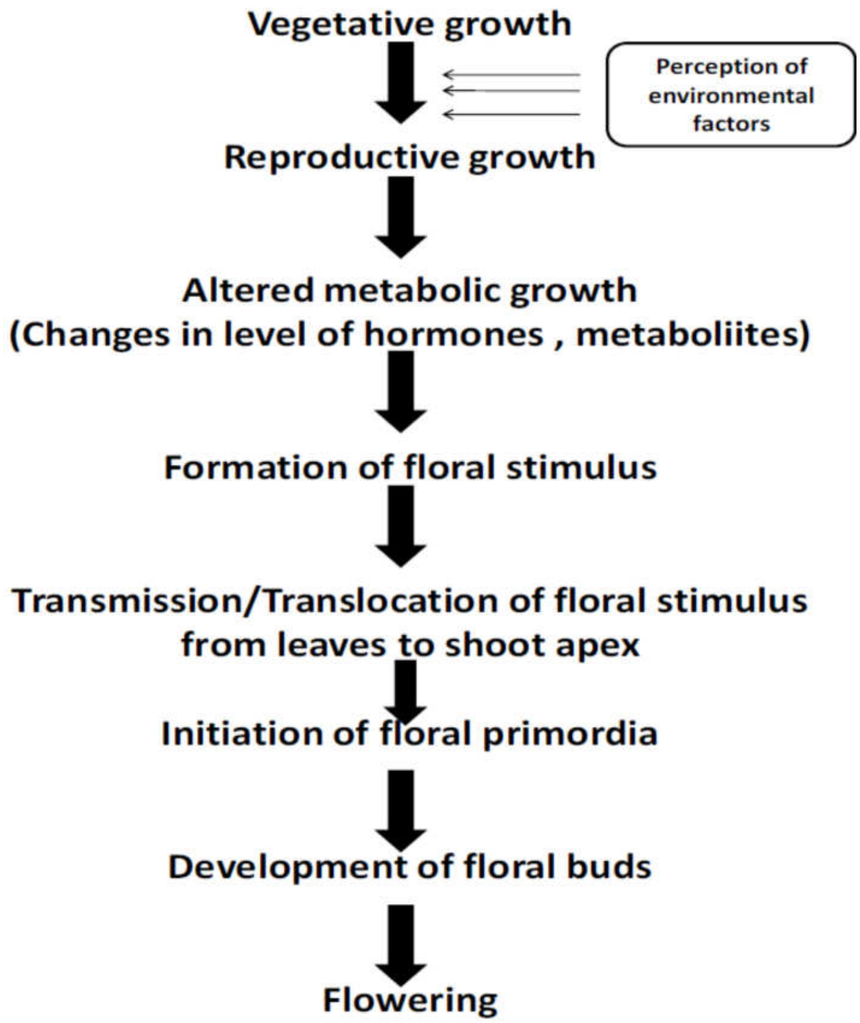


**Fig. 3.1: Outline of basic process leading to flowering in plants**

## 3.2 Photoperiodism

The term photoperiodism was suggested by Garner and Allard (1920) and the term photoperiodism refers to effect of length of day and night on growth and development of plants. Photoperiod is the favourable day length required by plants mainly for flowering to occur.

Garner and Allard (1920) first of all reported the phenomena of photoperiodism. They observed that mutant tobacco plant (Maryland mammoth) and soyabean (*Glycine max* ) follow seasonal dependent pattern of flowering. Effect of various environmental factors such as nutrition, soil moisture on flowering has been analyzed and it was found that none of these factors played a key role in regulating flowering. When plants were placed in dark and provided with shorter light period,

flowering was obtained in plants. After this, similar experiments were conducted on different plant species under different photoperiods (short - day, long - day) and found that it was length of day which control flowering in plant (Fig.3.2).
Depending upon the photoperiod requirement plants can be classified into these groups.

a) Short- day plant,
b) Long-day plant,
c) Day-neutral plants

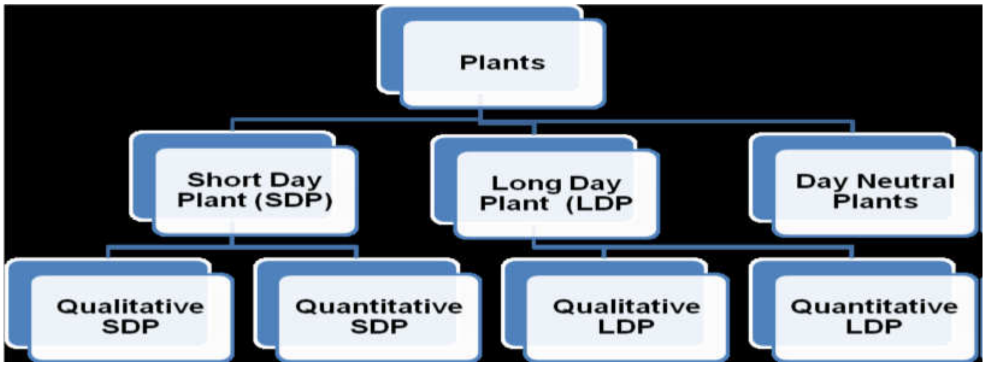


**Fig. 3.2: Classification of plants based upon photoperiod requirement for flowering**

1) **Short - day flowering plants**

These are those plants which flower when length of day is shorter than a critical period. These plants need a day length shorter than a critical period to flower. If day length exceeds a critical value then short-day flowering plants fail to flower. For example, in soybean day length of more than 12 hours effectively reduced number of flowers. These plants are also called as long night plants.

**Characteristic features of short-day flowering plants**

a) Short - day flowering plants (SDP) need continuous /uninterrupted long period of darkness to flower. Hence, you can say that in SDP length of day is not as important as period of darkness.
b) SDP will fail to flower if the continuous period of darkness is interrupted by weak intensity of light given for some time. The plant will also not flower even if a flash of light is given during period of darkness. Moreover, even if weak intensity (dim light) is given to plant for sometimes during the period of darkness flowering is inhibited (Fig. 10.3).

c) These plants can be made to flower in long day conditions as well by transferring to plants to darkness for sufficient duration.
d) It is obvious that length of night is more crucial for flowering in SDP than day length. If plants are kept in complete darkness and provided with sucrose externally. They exhibit normal pattern of flowering indicating that the photoperiod (day length) is required only for the process of photosynthesis (Hillman, 1959).
e) SDP do not flower under alternating cycles of lightness and darkness. The period of darkness which is needed by SDP for flowering showed be continuous. Suppose if a plant requires 16 hrs of darkness for flowering and the plant is given 16 hrs of darkness but not continuously instead in four instalments of 4 hrs each. Now the total period of darkness is 16 hrs but the plant fails to flower because period of darkness is not give continuously (Fig.16). Some examples of SDP are: tobacco (*Nicotiana tabacum*), soybean (*Glycine max*), strawberry (*Fragaria*), coffee (*Coffea arabica*), rice (*Oryza sativa*), *Bryophyllum*

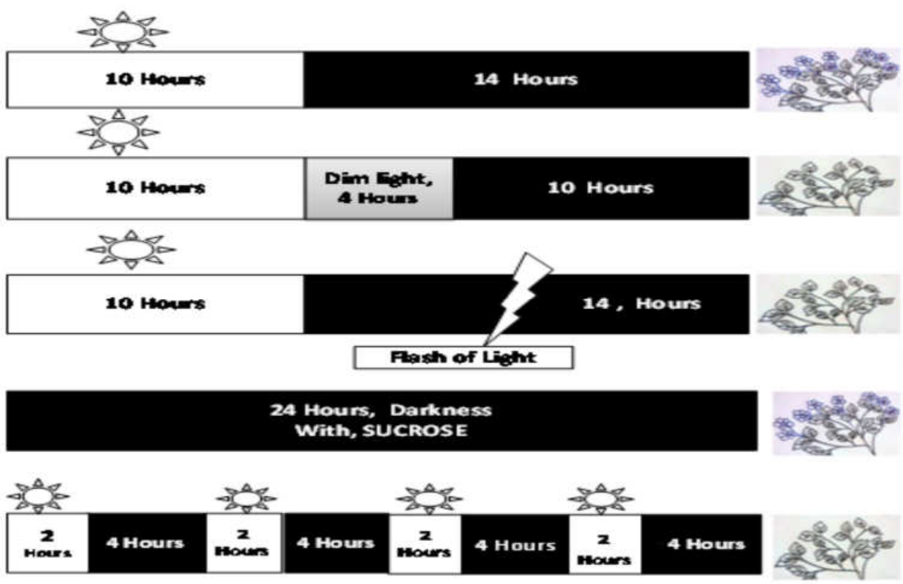


**Fig. 3.3: Effect of different photoperiod conditions on flowering in SDP**

**Types of SDP**

1) **Qualitative short - day plants**: Also called as absolute or obligatory short-day plants. These plants will flower only under short- day conditions and will never flower under unsuitable (other then absolute short- day) photoperiod e.g. strawberry (*Fragaria*), coffee (*Coffea arabica*).

2) **Quantitative short-day plant**: Also called as facultative short-day plant. These plants best flower under short-day conditions. However, they may also flower under long- day conditions but with delayed flowering e.g. cotton (*Gossypium hirsutum*).

**Short long-day plants**: Plant which flower when placed under short -day conditions followed by long days e.g. white clover (*Trifolium repens*).

2) **Long-day Flowering plants**

These are those plants which flower when provided with longer photoperiods. They need day length longer than a critical period to flower. More than, the requirement of longer photoperiod these plants require short period of darkness for flowering because larger period of darkness inhibits flowering in these plant. Hence, long-day plants are also called as short night plants.

**Characteristic features of long-day flowering plants:**

a) Long- day flowering plants flower best in continuous light. They either need little or no darkness for flowering.
b) Long period of darkness exhibits an inhibitory effect on flowering in long- day plants.
c) Long day- plants can flower in short -day (days shorter and nights longer) conditions if the period of darkness is interrupted by flash of light.
d) Unlike short-day plants long- day plants flower normally if light and dark period are provided alternately. Flowering occurs because dark period is not maintained for longer duration and hence cannot exhibit its inhibitory effect on flowering e.g. pea (*Pisum sativum*), peppermint (*Mentha piperita*), barley *(Hordeum vulgare*), rye Grass (*Lolium* spp.), wheat (*Triticum aestivum*), radish (*Raphanus sativus*).

Long- days plants flower when provided with a photoperiod of more then critical length. Period of darkness is believed to have somewhat inhibitory effect on flowering, hence if period of darkness extends beyond a limit flowering is inhibited. However, if a flash of light is given during the period of darkness, the inhibitory effect of darkness is compensated and their plant exhibits normal pattern of flowering. LDP also exhibits flowering kept under continuous light (without any period of darkness).

LDP will also flower if exposed to alternate period of light and darkness (Fig.3.4).

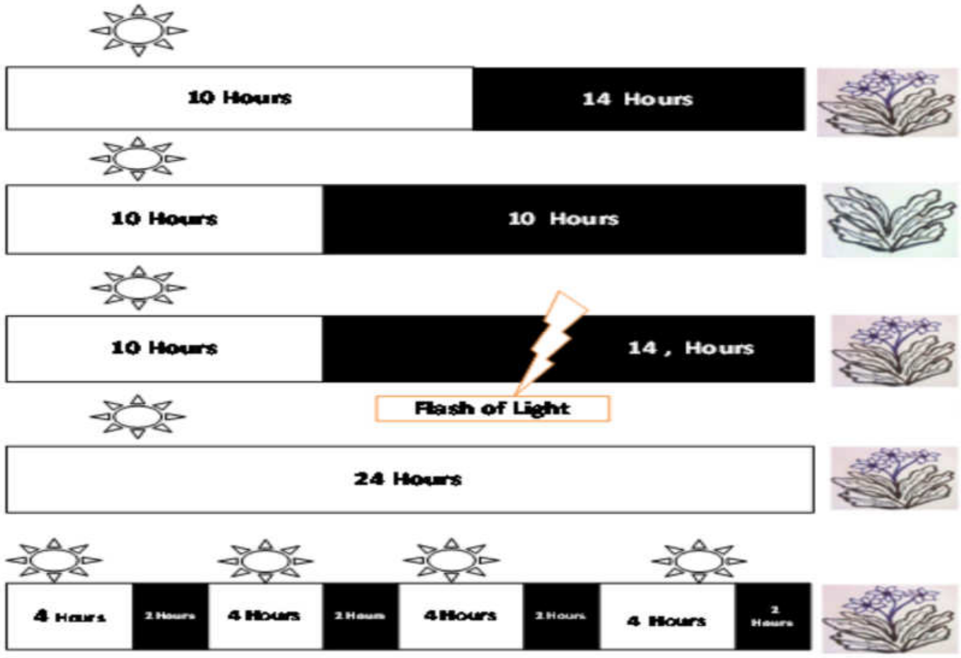


**Fig. 3.4: Effect of different photoperiod conditions on flowering in LDP**

**Types of LDP**

a) **Qualitative long-day plants**: These plants are also called as absolute long-day plants or obligatory long day plants. These are those plants which flower under only under long day conditions and will never flower under unsuitable / improper) photoperiod e.g. oat (*Avena sativa*), radish (*Raphanus sativus*)

b) **Quantitative long-day plants**: Also called as facultative long day plant. These are basically long day flowering plant and flower best under long day conditions. However they may also exhibit flowering under short day delayed conditions e.g. turnip (*Brassica rapa*), garden pea (*Pisum sativum*), spring wheat (*Triticum aestivum*).

**Long short-day plant:** plants which exhibited flowering when provided with long days followed by short day treatment / exposure e.g. Aloe (*Aloe bulbillifera*), Kalanchoe (*Kalanchoe laxiflora*).

3) **Day- neutral Plants**

These are those plants which can flower in all photoperiods. There is no seasonal preference for flowering in these plants e.g. tomato

(*Lycopersicon esculentum*), bean (*Phaseolus* spp.), cucumber *(Cucumis sativus*).

Normally short-day plants flower when day length is shorter than 11 hours and for long-day plants day length period of 14-16 hours is sufficient for flowering (Warner, 2006). However, day length may vary from species to species.

### 3.2.1 Significance of Photoperiodism

a) Photoperiodism determines the flowering season of a plant.
b) Knowledge of photoperiodism can be utilized in keeping plant in vegetative phase to obtain high yield of tubers rhizomes etc. or the plants may be maintained in reproductive stage to yield more flower and fruits.
c) Annuals can be grown more than once in a year by regulating photoperiod.
d) By increasing light hours winter dormancy and autumnal leaf fall can be prevented.
e) By providing requirement photoperiod plants can be made to flower throughout the year under green house.
f) Knowledge of photoperiodism is also useful in setting up of gardens, orchards etc.

The difference between photoperiodism and vernalization is given in Table 2.1 and difference between short-day plants and long-day plants has been given in Table 2.1.

**Table 2.1: Differences between Photoperiodism and Vernalization**

| S/No | Photoperiodism | Vernalization |
|---|---|---|
| 1. | It is response of length of light and dark on growth and development of plants | It is acceleration of flowering in plants by providing chilling treatment |
| 2. | Stimulus for photoperiodism is perceived by leaves | Stimulus is perceived by actively dividing cells (mostly meristems) |
| 3. | It prepares the plant for flowering and also initiates Flowering | It only prepares the plant for flowering |
| 4. | It is mediated via florigen | It is mediated via vernalin |

| | | | |
|---|---|---|---|
| 5. | Effect of photoperiod once perceived cannot be reserved | Effect of vernalization can be reserved by providing high temperature to plants |
| 6. | Photoperiodic stimulus can be transferred from plant to another by grafting | It cannot be passed through grafting except in *Henbane* |

**Table 2.2: Differences between short-day plants and long-day plants**

| S/No | Short -Day Plant | Long- Day plant |
|---|---|---|
| 1. | These plant exhibit flowering when exposed to day length shorter than a critical period | These plants flower when exposed to day length longer than a critical period |
| 2. | Generally flower in early spring or autumn | Generally flower in spring or early summar |
| 3. | Plants fail to flower if period of darkness is interrupted by flash of light | Flowering is stimulated if period of darkness is interrupted by flash of light |
| 4. | Gibberellic acid has no effect on flowering in SDP | Gibberellic acid exerts an inductive effect on flowering |

### 3.3 Phytochrome

Phytochrome is a pigment found in plants which is known to control development of plants. Phytochrome is a protein with chromatophore. The pigment exists in two interconvertable forms PR and PFR. The type of phytochrome which absorbs red light is called as PR and the type of phytochrome which absorbs far-red light if called PFR. PR is red light sensitive and PFR is far red light sensitive. Plant utilizes phytochrome to sense the seasonal changes in night length or photoperiod (Fig.3.5).
Phytochrome is mainly produced during darkness and firstly exists as PR (P600). When exposed to light of wavelength 660nm (red) it is converted into PFR (P730). PFR can be reconverted to PR if exposed to wavelength of 730nm. Among both the forms of phytochrome, PR is biologically inactive whereas PFR is biologically active. Many of the physiological changes occurring in plants such as pigmentation, hypocotyls - hook opening, unfolding of leaves (in seedlings), photomorphogenesis, photoperiodism and many others are influenced by phytochrome.

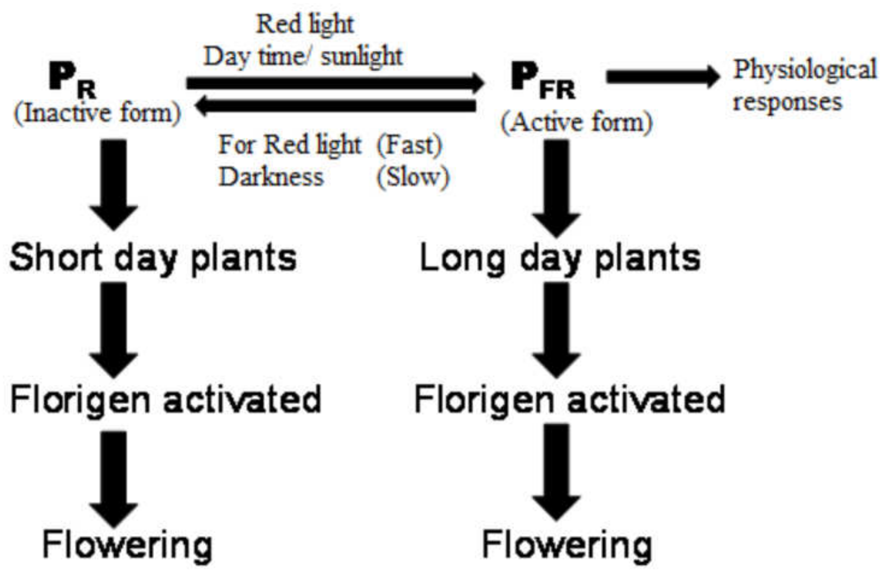


**Fig. 3.5: Interconvertable forms of phytochrome**

### 3.3.1 Effect of phytochrome on flowering in SDP

As you have already seen that short-day plants are those plants which show normal flowering when exposed to shorter photoperiod and longer period of darkness. It has already been discussed that longer period of darkness is crucial for flowering to occur in SDP. If the longer period of darkness is interrupted by red light, SDP fail to flower. However, if red light treatment is followed by far red, the inhibitory effect of red right is compensated and plants show normal flowering. If SDP are given alternate treatment of far and far red light then the treatment given in the last will show its effect.

### 3.3.2 Effect of phytochrome on flowering in LDP

We have already discussed that long-day plants are those which flower when provided with longer period of light and shorter period of darkness. You have also seen that longer period of darkness has an inhibitory effect on flowering in LDP. If LDP is exposed to longer period of darkness it will not flower. However, this longer period of darkness is interrupted by red light, plants show normal flowering as because the period of continuous darkness is not maintained. Red light breaks the longer period of darkness into two shorter periods and hence period of darkness loses its inhibitory effect and flowering occurs. But if red light is followed by far red, the effect of red light is counter acted by far red and red light does not show its effect. As a result, the longer period of darkness can maintain its inhibitory effect and plant fails to flower. As seen in the case of SDP, if Red and far red light are given alternately than the last treatment provided to the plant will exert its effect (Fig.3.7)

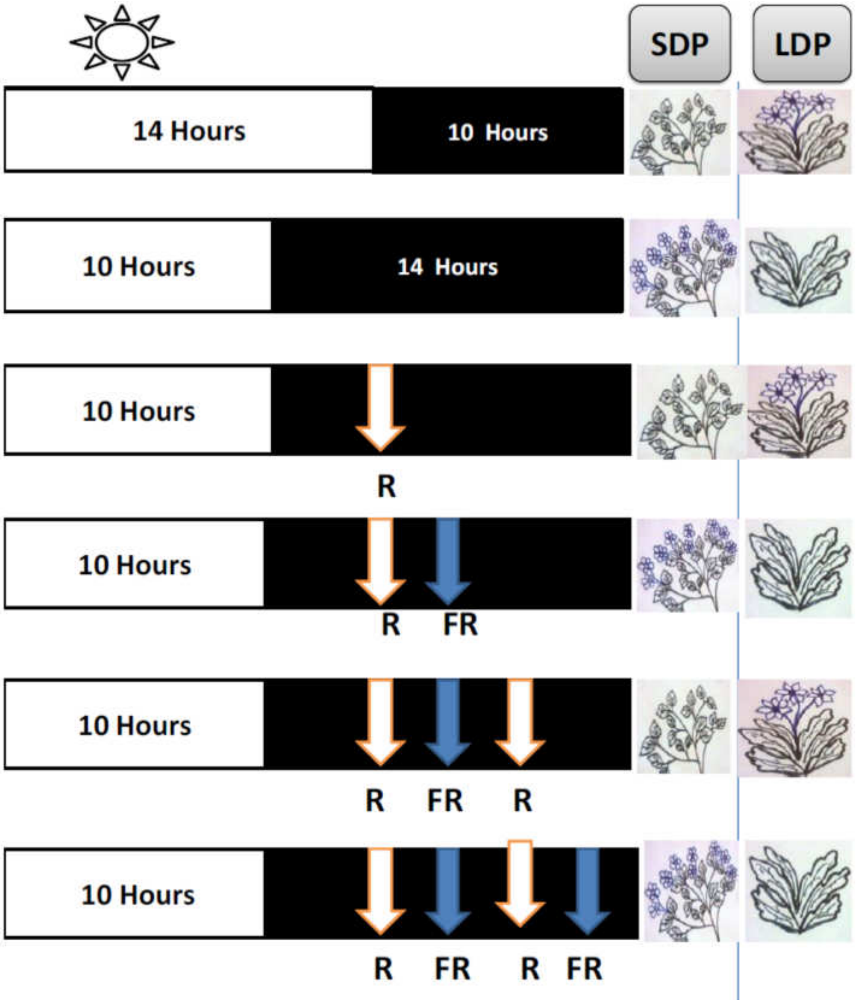


**Fig. 3.7: Effect of PR & PFR on flowering in SDP and LDP**

**Other Factors Influencing Flowering in Plants**

**(a) Effect of plant growth regulators**

**Gibberellic acid** has been reported to have a positive influence on flowering in long-day plants. There are several long-day plants which under unfavourable conditions (short day condition) provided will gibberellic acid exhibit normal flowering. Flowering inducing effect of gibberellin have been observed only in long-day plants and not in short-day plants. However application of GA in SDP will cause stem elongation.

In the presence of red light the precursor is converted into GA like hormone and far red light inhibits the action of Gibberellic acid as in the presence of far red light gibberellin like hormone is converted back to the precursor. *Arabidopsis thaliana*, *Hyoscyamus niger, Lactuca sativa* are some of long-day plants which can be made to flower under short day condition by exogenous application of gibberellic acid. Plants belonging to family Cupressaceae, Taxodiaceae and Pinaceae also show flowering induced by GA.

**Auxins** have been reported to induce flowering in pine apple, *Hysocyamus niger*, wintex barley. Flower inducing effects of auxin on pine apple was discovered in 1942 and since then auxin have been commercially utilized to induce flowering in pine apple varieties. However, auxin has been found to have different response in different plant species. In some plants auxin helps in inducing flowering whereas in other plant it inhibits flowering or have no effect on flowering. It is expected that the plants in which auxin inhibits flowering is via. ethylene production as it is well known that application of auxin leads to production of ethylene.

Similarly**, Cytokinin** have been reported to induce flowering in plant varieties such as *Lemna paucicostata, Perilla, Wolffia, Chrysanthemum* etc. flowering in these plant have been achieved even under non inductive photoperiods by utilization of cytokinin. However, as you have seen in case of auxin that in some plants it induces flowering and in some plants it inhibits flowering. Similarly, cytokinin may also inhibit flowering in some plants. One such plant is *Chenopodium* in which flowering is inhibited in presence of cytokinin.

**Abscissic acid** cannot induce flowering if the required photoperiod is not provided, however application of abscissic acid under favourable photoperiod enhances reproductive development. *Chenopodium* and *Pharbitis nil* are two such plant species in which flowering in enhanced in favourable season by application of abscissic acid.

**Salicylic acid** has been known to act as plant growth regulator. Most of the plants do not have a requirement of salicylic acid for flowering however it has been reported to enhance flowering in plants such as *Lemna*. **Ascorbic acid** have also been reported to induce in flowering in plants like *Brassica* and *Lemna*.

**(b) Increased Carbon: Nitrogen Ratio**

Many scientists including Kraus and Bill have proposed that C/N ratio is also significant in determination of flowering in plants. They conducted their study on tomato plants and have proposed following effects of C/N ratio on plants.

## 3.4 Vernalization

Vernalization can be defined as a process or method of inducing early flowering in plants. It is achieved mainly by treatment of seeds at very low temperature.

Generally, you may consider growth and development to be more or less similar; however both (growth and development) are different processes. Growth generally refers to increase in size and weight whereas development includes processes such as differentiation in flowering, pollination and fertilization which ultimately leads to reproduction. Lysenko in 1920-30 postulated the main principle of vernalization. The basic concept remains that by providing specific treatment either to germinating seed or to the plant one of the two phase of life cycle of plant (i.e. growth and development) can be favored. For example winter wheat is normally grown in winter season but if the seeds of the plant are allowed to germinate in ice box with appropriate suitable light moisture and air, they can be grown in summer as well along with normal flowering.

Flowering is one of the most important process in life cycle of plant since it is the key event for reproductive succession in plants. Most of the plants flower only when they are exposed to proper period of light. Long-day flowering plants need short period of darkness to flower whereas short-day plants require longer period of darkness (continuous) to exhibit flowering. However, day neutral plants are independent of photoperiod and flower irrespective of day night length. There is no doubt about the photoperiod (duration of light to which plant is exposed) remains to the most crucial important factor for following to occur. Beside this, temperature is another factor which also has significant effect on flowering.

If you consider flowering in annuals and biennials, for annuals photoperiod is most crucial for flowering, followed by temperature. However in the case of biennials as you know that biennials are those plants which show vegetative growth in first season and when they have gone through prolonged exposure to low temperature during winter season, they exhibit flowering in next season. If due to any reason these plants do not get exposure to low temperature they fail to flower and will continue to grow vegetatively. However they can be made to flower of the plants that are exhibited to cold treatment following suitable photoperiod. Many biennials such as carrot, cabbage, beet, glove needs cold treatment for flowering to occur.

### 3.4.1 Process of Vernalization

Vernalization can be achieved by a very simple process. Seeds to be vernalized should be soaked in water properly, vernalization can never be achieved in dry seeds, it has been reported that seed should contain about 90% water of their dry weight. Seeds then allowed to germinate, followed by treatment of low temperature for suitable period of time. Treated seedlings are slightly dried and then sown for further growth (Fig. 3.8).

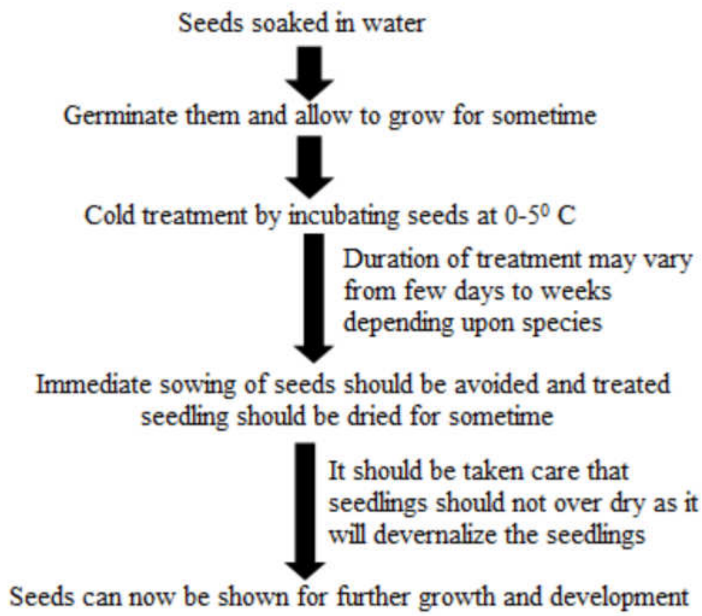


**Fig. 3.8: Outline of basic process to achieve vernalization**

**Requirement of vernalization**

i) **Low temperature:** Normally vernalization is achieved in temperature range of zero degree to 10°C, when the temperature is decreased below 0°C the effectiveness of vernalization generally decreases and at about -6°C there is no effect and vernalization cannot be achieved.

ii) **Duration of treatment:** The time period required for vernalization may vary from species to species and can range from few days to few weeks. Normally the time period of treatment is long since vernalization is considered to be a slow process.

**iii)** **Actively dividing cells:** Since vernalization cannot occur in dry seeds due to absence of active embryo, after germination embryo becomes active and can perceive vernalization. In whole plant vernalization signal is perceived by meristematic cells (shoot tips, root apex, developing leaves) shoot apical meristem of *Chrysanthemum* have been demonstrated to perceive vernalization.

**iv)** **Water:** Water is an essential requirement for germination and that seeds provided with vernalization treatment also requires water for germination and growth.

### 3.4.2 Devernalization and Revernalization

Devernalization can be defined as a process in which vernalized seeds / seedlings loses their vernalized states and becomes devernalized. Over drying of vernalized seed / seedling, heat treatment of vernalized seed/ seedling may result in devernalization. An atmosphere of nitrogen in presence of high concentration of $CO_2$ may also result in devernalization. However, devernalized seeds can be easily revernalized by subjecting them to low temperature. Vernalization response critically depends upon the temperature to which seeds are exposed and also on the duration for which the treatment is maintained. If either of them (temperature or duration) falls short of the requirements then either vernalization may not occur properly or the vernalized seed may be easily devernalized.

**Advantages of Vernalization**

1) Vernalization shortens the Juvenile or vegetative phase and induces early flowering.
2) Vernalization can be applied to temperate as well as tropical plants.
3) Vernalization is expected to increase resistance to cold and diseases.
4) Biennials can be made to behave as an annual that is flower in one growing season.
5) Early flowering and fruit setting can be achieved in biennials.
6) Plants can also be made to grow in regions where they normally do not grow.
7) It can be used in Horticulture. Flowering can be induced into non vernalization plant by grafting a vernalized shoot open.

When proper cell treatment is provided a stimulus is perceived by the dividing cell. Researchers have named the stimulus as vernalin. Formation of vernalin alone is not enough for flowering to occur. After vernalization plants appropriate photoperiod is also required (it should be noted here that proper vernalization only prepares the plant to flower however, photoperiodism provides stimulus for flowering and also induces the flowering). Following proper photoperiod either vernalin is converted into florigen or vernalin regulates florigen synthesis. Florigen once produced directs reproductive development and flowering is initiated in the plants.

**SELF-ASSESSMENT EXERCISE**

- What is photoperiodism? Classify plants based upon their photoperiodic requirement for flowering?
- Define devernalization. How it can be achieved?
- Differentiate between:
  a) Long-day Plant and short-day plants
  b) Photoperiodism and vernalization
  c) Obligate SDP and Facultative SDP
  d) Qualitative LDP and Quantitative LDP

## 4.0 CONCLUSION

In this unit, it is said that when plant has completed certain vegetative growth, it makes a transition from juvenile stage of maturity. Most of the plants require favourable environmental to occur. Photoperiod and temperature are the most crucial environmental factors for flowering. The response of plants to day length is known as photoperiodism. Depending upon requirement of photoperiod plants can be short -day plants, long-day plants and day neutral plants. Short - day plants flower when a critical period of darkness is exceeded. Long-day plants exhibit flowering when period of darkness is less than a critical period. When exposed to suitable photoperiod, the photoperiodic stimulus is perceived by leaves and a flowering hormone (florigen) is synthesized. Flowering hormone is translocated to shoot apex where bud formation and flowering takes place.

## 5.0 SUMMARY

Flowering crucially depends upon developmental status of plants among different environmental factors, length of days, quality and intensity of light and temperature are among the most important factors which control flowering in plants. Phytochrome is a protein with chromatophore found in plants in two interconvertable forms: PR and PFR. PR is red light sensitive and PFR is far red light sensitive. Among the two forms of phytochrome PFR is biologically active form. Some plants require exposure to low temperature (vernalization) for flowering to occur. The effect of temperature on flowering is more profound in biennials as compared to annuals. Temperature in range of 0-5ºC is considered to be most effective to achieve vernalization. Effect of vernalization can be reversed (devernalization) by exposing vernalized seed or plant to high temperature.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Define Phytochrome and discuss the effect of different types of phytochrome on flowering in plants?
2. What is photoperiodism? Classify plants based upon their photoperiodic requirement for flowering?
3. Define devernalization. How it can be achieved?
4. Differentiate between:
   e) Long-day Plant and short-day plants
   f) Photoperiodism and vernalization
   g) Obligate SDP and Facultative SDP
   h) Qualitative LDP and Quantitative LDP

## 7.0 REFERENCES/FURTHER READING

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**MODULE 4 MINERAL NUTRITION OF PLANTS: FUNCTIONS AND DEFICIENCY SYMPTOMS OF NUTRIENTS, NUTRIENT UPTAKE MECHANISMS**

## UNIT 1 MEANING OF MINERAL NUTRITION

**CONTENTS**



## 1.0 INTRODUCTION

Mineral nutrients are elements acquired primarily in the form of inorganic ions from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense plants act as the "miners" of Earth's crust. The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution make mineral absorption by plants a very effective process.

After being absorbed by the roots, the mineral elements are translocate to the various parts of the plant, where they are utilised in numerous biological functions. Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with mots in the acquisition of nutrients. The study of how plants obtain and use mineral nutrients is called mineral nutrition.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Explain the meaning of mineral nutrition
- Outline the classification of essential elements into two groups
- Discuss the criteria of essentiality of mineral elements
- Classify plant nutrients based on their biochemical role and physiological function
- Discuss the mineral availability shows an interesting dose effect
- List the specific roles of essential mineral elements
- Explain the physiology of nutrient uptake

## 3.0 MAIN CONTENT

### 3.1 Meaning of Mineral Nutrition

The chemical compounds required by an organism are termed as nutrients

1. Nutrition may be defined as the supply and absorption of chemical compounds needed for plant growth and metabolism
2. For plant growth and metabolism, 17 elements are essential.

They are C, H, O, N, P, K, Ca, S, Mg, Fe, Mn, Zn, B, Cu, Mo, Cl and Ni. These essential elements are classified into two groups

i. Major elements (macro nutrients)
ii. Minor elements (Micro nutrients) (Trace elements)

**Major elements**

The essential elements which are required by the plants in comparatively large amounts are called as major elements or macro nutrients. According to another definition minerals found in >1000 ppm concentration are macronutrients. They are C, H, O, N, P, K, Ca, S, Mg.

**Minor elements**

The essential elements which are required in very small amounts or traces by the plants are called as minor elements or micronutrients or trace elements. According to another definition minerals found in <100 ppm concentration are micronutrients. They are Fe, Zn, Mn, B, Cu and Mo. Si is now transferred from list of beneficial elements to essential elements.

**Beneficial elements:** (Na, Si and Co)

Sodium has beneficial effect, and, in some case, it is essential. There are some plant species, particularly the Chenopodiaceous plants and species adapted to saline conditions that take up this element in relatively high amounts. Na is also required for turnips, sugar beets and celery. The same is true for Si, which is an essential nutrient for rice. Cobalt is an essential element for the growth of the Blue green algae, but it has not been shown to be essential for other algae or for higher plants. It is also required by certain legumes to fix atmospheric nitrogen. Here, however the cobalt ion is necessary for the symbiotic bacteria present in the nodules associated with the roots.

### 3.1.1 Criteria of Essentiality of Mineral Elements

The term essential mineral element was proposed by Arnon and Stout (1939). According to them an element to be considered essential, three criteria must be met:

1. A given plant must be unable to complete its life cycle in the absence of mineral elements.
2. The function of the element must not be replaceable by another mineral element
3. The elements must be directly involved in plant metabolism.

For e.g., as a component of an essential plant constituents or it must be required for a distinct metabolic step such as an enzyme reaction.

Based on the mobility, elements are also classified into three types.

1. Mobile elements: N, P, K, S and Mg
2. Immobile elements: Ca, Fe and B
3. Intermediate in mobility: Zn, Mn, Cu, Mo

### 3.1.2 Classification of Plant Nutrients Based on their Biochemical Role and Physiological Function

Essential elements are now classified according to their biochemical role and physiological function. Based on the biochemical behavior and physiological functions, plant nutrients may be divided into four groups.

**Table 4.1: Nutrient Elements Uptake and Biochemical Function**

| Nutrient Elements | Uptake | Biochemical functions |
|---|---|---|
| 1st group<br>C, H, O. N, S | In the form of $CO_2$, $HCO_3^-$, $H_2O$, $O_2$, $NO_3$, $NH^+$, $N_2SO_4$, $SO_2$. The ions from the soil solution, the gases from the atmosphere | Major constituents of the organic compounds of the plant. Essential elements of atomic groups which are involved in enzymatic processes. Assimilation by oxidation reduction reactions. |
| 2nd Group<br>P, B, Si | In the form of phosphates, boric acid or borate, silicate from the soil solution. | They are important in energy storage reactions or in maintaining structural integrity. Elements in this group are often present in |

| | | |
|---|---|---|
| | | plant tissues as phosphate, Borate and silicate esters in which the elemental group is bound to the hydroxyl group of an organic molecule (i.e., sugar- phosphates) (Esterification*). The phosphate esters are involved in energy transfer reactions. |
| 3rd Group<br>K, Na, Mg, Ca, Mn, Cl | In the form of cations from the soil solution except chlorine | Present in plant tissues as either free ions or ions bound to substances such as the pectic acids present in the plant cell wall. Of particular importance of their roles as enzyme cofactors and in regulation of osmotic potentials. |
| 4th Group<br>Fe, Cu, Zn, Mo | In the form of ions or chelates from the soil solution | Present predominantly in a chelated form Incorporated in prosthetic groups. Enable electron transport by valency change. |

(Source: Taiz and Zeiger, 2002)

*Esterification: Compounds formed by condensation of an acid and alcohol with elimination of water ADP + Pi = ATP

## 3.2 Mineral Deficiencies Produce Visible Symptoms

When minerals are deficient, the growth of the plant is stunted, or the plant shows other symptoms. The combination of symptoms observed for deficiency of a particular mineral can be traced to the roles that mineral plays in metabolism or physiology.

1. **Stunted growth** is a symptom for many deficiencies, especially stunted stems with nitrogen deficiency and stunted roots in phosphorus deficiency.
2. **Chlorosis** decreased chlorophyll synthesis or increased chlorophyll degradation, is observed with magnesium, nitrogen, and iron deficiencies. Magnesium is the central atom for the

electron cloud of chlorophyll from which electrons flow through the light reactions.

3. **Necrosis**, dead spots or zones, is observed when magnesium, potassium or manganese deficiencies are present.
4. Colour changes such as excessive **anthocyanin production** are observed in stems with phosphorus deficiency. They generally pick up an intense purple Colour sometimes extending onto the leaves.

### 3.2.1 Mineral Availability Shows an Interesting

**i. Dose Effect:**

The following graph demonstrates how deficiency reduces growth. As the mineral availability is increased, growth increases. As the mineral content continues to be increased there is no further increase in growth, but quality may be continuing to increase. This zone is called the luxury zone. However, continuing to increase the mineral concentration ultimately reaches toxic levels and growth is diminished.

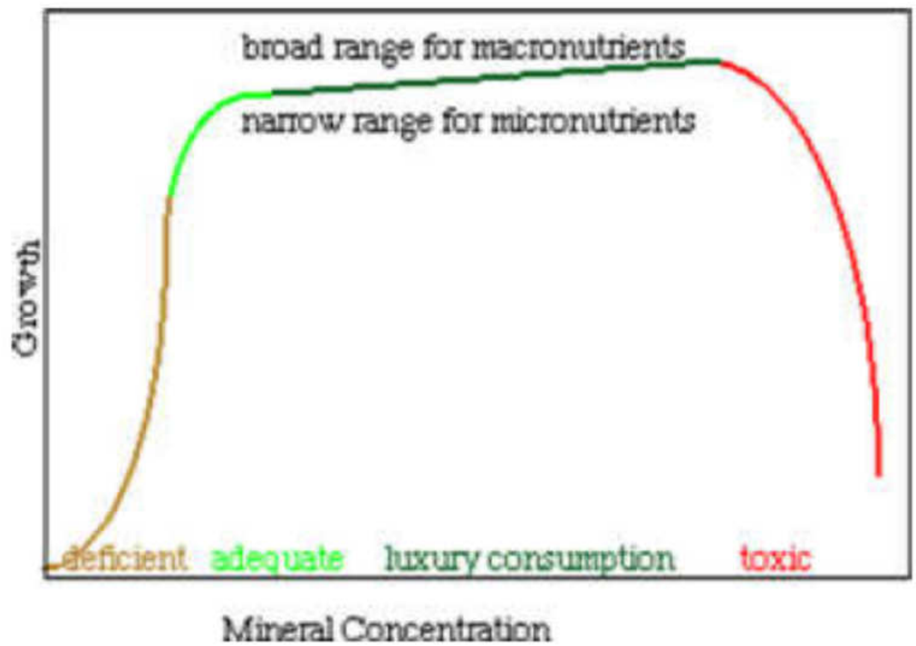



**Fig. 4.1: Graph Showing Defiency Reduces Growth**

The goal of a plant grower is to keep the plant in the sufficient to luxury zone but never to get as low as deficiency or as high as toxicity for any one of the macronutrients or micronutrients.

The trouble with that goal knows how wide the luxury zone is in terms of concentrations. For minerals like boron, the zone is very narrow, and it is easy to achieve toxic levels or to be in deficiency. For minerals like phosphorus, the luxury zone is quite broad and large amounts can be given and the plants will respond nicely in spite of that. As a result, it is difficult to overdose plants on phosphorus.

### 3.2.2 Specific Roles of Essential Mineral Elements

#### A. The macronutrients

1. **Nitrogen specific role**

- Nitrogen is important constituent of proteins, nucleic acids, porphyries (chlorophylls & cytochromes) alkaloids, some vitamins, coenzymes etc. Thus, N plays very important role in metabolism, growth, reproduction and heredity.

**Deficiency symptoms**

- Plant growth is stunted because protein content cell division and cell enlargement are decreased
- N deficiency causes chlorosis of the leave i.e., yellowing older leaves are affected first
- In many plants e.g., tomato, the stem, petiole and the leaf veins become purple colored due to the formation of anthocyanin pigments.

2. **Phosphorus**

- It is important constituent of nucleic acids, phospholipids, coenzymes NADP, NADPH2 and ATP
- Phospholipids along with proteins may be important constituents of cell membranes
- P plays important role in protein synthesis through nucleic acids and ATP
- Through coenzymes NAD, NADP and ATP, it plays important role in energy transfer reactions of cell metabolism e.g., photosynthesis, respiration and fat metabolism etc.

**Deficiency symptoms**

- P deficiency may cause premature leaf fall
- Dead necrotic areas are developed on leave or fruits
- Leaves may turn to dark green to blue green Colour. Sometimes turn to purplish Colour due to the synthesis and accumulation of anthocyanin pigments.

3. **Potassium Specific role:**

- Although potassium is not a constituent of important organic compound in the cell, it is essential for the process of respiration and photosynthesis
- It acts as an activator of many enzymes involved in carbohydrate metabolism and protein synthesis

- It regulates stomata movement
- Regulates water balance

**Deficiency symptoms**

- Mottled chlorosis of leaves occurs
- Neurotic areas develop at the tip and margins of the leaf
- Plants growth remains stunted with shortening of internodes.

4. **Calcium**

- It is important constituent of cell wall
- It is essential in the formation of cell membranes
- It helps to stabilise the structure of chromosome
- It may be an activation of may enzymes deficiency symptoms

**Deficiency symptoms**

- Calcium deficiency causes disintegration of growing meristematic regions of root, stem and leaves
- Chlorosis occurs along the margins of the younger leaves
- Malformation of young leaves takes place

5. **Magnesium**

- It is very important constituent of chlorophylls
- It acts as activation of many enzymes in nucleic acid synthesis and carbohydrate metabolism
- It plays important role in binding ribosomal particles during protein synthesis.

**Deficiency symptoms**

- Mg deficiency causes mottled chlorosis with veins green and leaf tissues yellow or white appearing first on older leaves
- Dead neurotic patches appear on the leaves
- In cotton Mg deficiency leads o reddening of leaves and disorder is called as reddening in cotton.

6. **Sulphur specific role**

- It is important constituent of some amino acids (cystine, cysteine and methionine) with which other amino acids form the protein
- S helps to stabilise the protein structure
- It is also important constituent of vitamin i.e., biotin, thiamine and coenzyme A
- Sulfhydryl groups are necessary for the activity of many enzymes.

**Deficiency symptoms**

- Deficiency causes chlorosis of the leaves
- Tips and margins of the leaf roll in ward
- Stem becomes hard due to the development of sclerenchyma.

**B. Micronutrients:**

1. **Iron specific role:**

- Important constituent of iron porphyrin proteins like cytochromes, peroxidases, catalases, etc.
- It is essential for chlorophyll synthesis
- It is very important constituent of ferredox in which plays important role in photochemical reaction in photosynthesis and in biological nitrogen fixation.

**Deficiency symptoms**

- Iron deficiency causes chlorosis of young leaves which is usually interveinal.

2. **Zinc specific role:**

- It is involved in the biosynthesis of growth hormone auxin (indole 3 acetic acid)
- It acts activator of many enzymes like carbonic anhydrase an alcohol dehydrogenase, etc.

**Deficiency symptoms**

- Zinc deficiency causes chlorosis of the young leaves which starts from tips and the margins
- The size of the young leaves is very much reduced. This disorder is called as 'little leaf disease'
- Stalks will be very short.

3. **Manganese**

- It is an activator of many respiratory enzymes
- It is also an activator of the enzyme nitrite reductase
- It is necessary for the evolution of oxygen (photolysis) during photosynthesis

**Deficiency symptoms**

- The young leaves are affected by mottled chlorosis
- Veins remain green
- Small necrotic spots developed on the leaves with yellow strips

4. **Copper specific role**

- It is an important constituent of plastocyanin (copper containing protein)
- It is also a constituent of several oxidizing enzymes.

**Deficiency symptoms**

- Copper deficiency causes necrosis of the tip of the young leaves
- It also causes die-back of citrus and fruit trees

- Also causes reclamation disease or white tip disease of cereals and leguminous plants.

5. **Boron specific role**

- Boron facilitates the translocation of sugars by forming sugar borate complex.
- It involves in cell differentiation and development since boron is essential for DNA synthesis
- Also involves in fertilization, hormone metabolism

**Deficiency symptoms**

- Boron deficiency causes death of shoot tip
- Flower formation is suppressed
- Root growth is stunted
- The other diseases caused by B deficiency is Heart rot of beet, Stem crack of celery, Brown heart of cabbage, Water core of turnip, Internal cork formation in apple, Hen and chicken in grapes.

6. **Molybdeneum**

- It is constituent of the enzyme nitrate reductase and thus plays an important role in nitrogen metabolism
- It is essential for flower formation and fruit set.

**Deficiency symptoms**

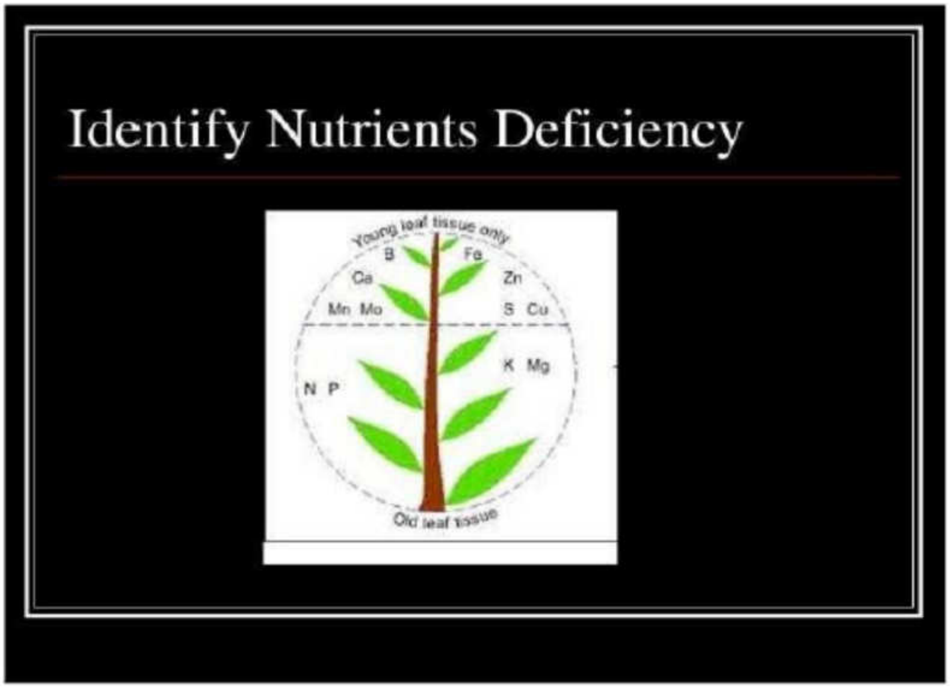
- Molybdenum deficiency causes interveinal chlorosis of older leaves
- Flower formation is inhibited
- Causes whiptail disease in cauliflower plants.

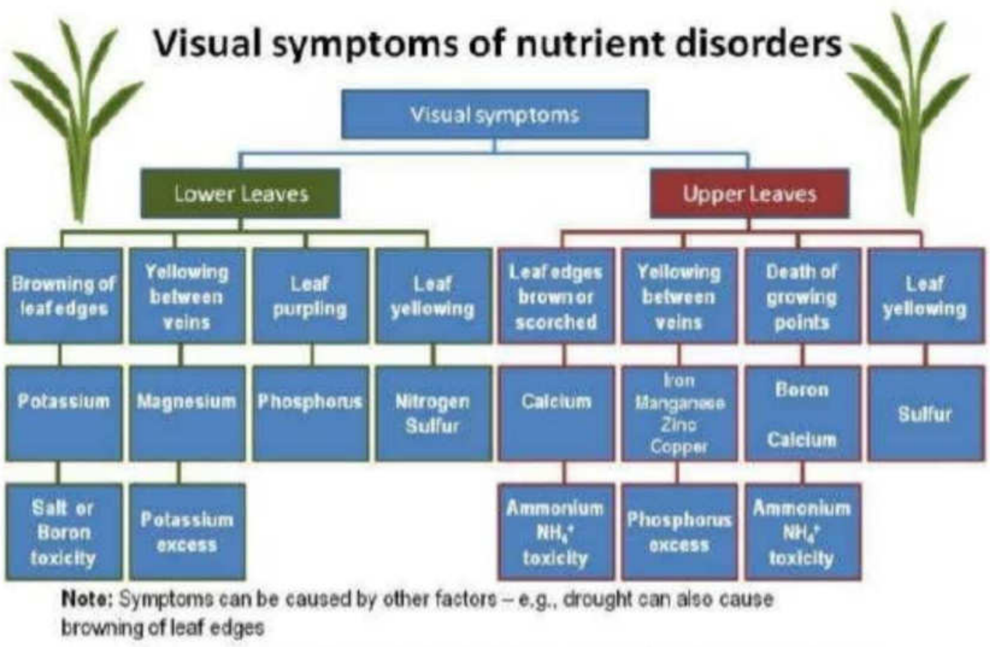
7. **Chlorine: Specific role**

- Chlorine has been shown to be involved in the oxygen evolution in photosystem II in photosynthesis (Cl and Mn are important for this reaction)
- It raises the cell osmotic pressure
- Chlorine accelerates the activation of amylase which converts starch into soluble sugars

**Deficiency symptoms**

- Chlorosis of younger leaves and an overall wilting of the plant
- In some plant species, like tomato, leaves show chlorotic mottling, bronzing and tissue necrosis




Source: Modified from T.H. Fairhurst, C. Witt, R.J. Buresh, and A. Dobermann (eds). 2007. *Rice: A Practical Guide to Nutrient Management (2nd edition).* International Rice Research Institute (IRRI), Philippines

**DEFICIENCIES OF NUTRIENT ELEMENTS**

| Symptoms | Suspected Element | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Mg | Fe | Cu | Zn | B | Mo | Mn | OF |
| Yellowing of Younger Leaves | | | | | ✓ | | | | | ✓ | |
| Yellowing of Middle Leaves | | | | | | | | | ✓ | | |
| Yellowing of Older Leaves | ✓ | | ✓ | ✓ | | | ✓ | | | | |
| Yellowing Between Veins | | | | ✓ | | | | | | ✓ | |
| Old Leaves Drop | ✓ | | | | | | | | | | |
| Leaves Curl Over | | | | ✓ | | | | | | | |
| Leaves Curl Under | | | ✓ | | | ✓ | | | | | ✓ |
| Younger Leaf Tips Burn | | | | | | | | ✓ | | | |
| Older Leaf Tips Burn | ✓ | | | | | | ✓ | | | | |
| Young Leaves Wrinkle/Curl | | | ✓ | | | | ✓ | ✓ | ✓ | | |
| Necrosis | | | ✓ | ✓ | ✓ | | ✓ | | | ✓ | |
| Leaf Growth Stunted | ✓ | ✓ | | | | | | | | | |
| Dark Green/Purple Leaf & Stems | | ✓ | | | | | | | | | |
| Pale Green Leaf Color | ✓ | | | | | | | | ✓ | | |
| Molting | | | | | | | ✓ | | | | |
| Spindly | ✓ | | | | | | | | | | |
| Soft Stems | ✓ | | ✓ | | | | | | | | |
| Hard/Brittle Stems | | ✓ | ✓ | | | | | | | | |
| Growing Tips Die | | | ✓ | | | | | ✓ | | | |
| Stunted Root Growth | | ✓ | | | | | | | | | |
| Wilting | | | | | | ✓ | | | | | |

Source: Modified from T.H. Fairhurst, C. Witt, R.J. Buresh, and A. Dobermann (eds). 2007. *Rice: A Practical Guide to Nutrient Management (2nd edition)*. International Rice Research Institute (IRRI), Philippines

## 3.3 Physiology of Nutrient Uptake

Mineral nutrients are found either as soluble fractions of soil solution or as adsorbed ions on the surface of colloidal particles. Various theories proposed to explain the mechanism of mineral salt absorption can be placed in two broad categories:

- Passive Absorption
- Active Absorption

**Ion uptake is both active and passive:**

After several decades of research on this process of ion uptake it is now believed that the process involves both passive and active uptake mechanisms.

Whether a molecule or ion is transported actively or passively across a membrane (casparian band, plasma membrane or tonoplast) depends on the concentration and charge of the ion or molecule, which in combination represent the electrochemical driving force.

Passive transport across the plasma membrane occurs along with the electrochemical potential. In this process ions and molecules diffuse from areas of high to low concentrations. It does not require the plant to expend energy.

Active transport, (in contrast, to passive transport) energy is required for ions diffusion against the concentration gradient (electro chemical potential). Thus, active transport requires the cell to expend energy.

### 3.3.1 Passive Transport Mechanism

A. Diffusion: Simple diffusion to membranes occurs with small, non-polar molecules (i.e., $O_2$, $CO_2$). In this process ions or molecules move from the place of higher concentration to lower concentration. It needs no energy.

B. Facilitated diffusion: For small polar species (i.e., $H_2O$, Ions and amino acids) specific proteins in the membrane facilitate the diffusion down the electrochemical gradient. This mechanism is referred to as facilitated diffusion.

   a) Channel proteins: The specific proteins in the membrane form channels (channel proteins), which can open and close, and through which ions or $H_2O$ molecules pass in single file at very rapid rates. A K+ and NH4+ channel also operates by the same process of facilitated diffusion. In addition, Na+ can also enter the cell by this process.

   b) Transporters or Co-transporters or carriers: Another mechanism involves transporters or co-transporters responsible for the transport of ions and molecules across membranes. Transporter proteins, in contrast to channel proteins, bind only one or a few substrate molecules at a time. After binding a molecule or ion, the transporter undergoes a structural change specific to a specific ion or molecule. As a result, the transport rate across a membrane is slower than that associated with channel proteins.

Three types of transporters have been identified:

1) Uniporters: transport one molecule (i.e., glucose, amino acids) at a time down a concentration gradient.
2) Antiproters: catalyze movement of one type of ion or molecule against its concentration gradient. This is coupled with the movement of a different ion or molecule in the opposite direction. Examples of antiporter transport are $H^+/Na^+$ and $H^+/Ca^{2+}$ transport into the vacuole.
3) Symporters: catalyze movement of one type of ion or molecule against its concentration gradient coupled to movement of a different ion or molecule down its concentration gradient in the same direction. The high $H^+$ concentration in the apoplast provides the energy for symporter transport of $NO^-$ and the other anions.

Therefore, the energy for antiporter and symporter transport originates from the electric potential and/or chemical gradient of a secondary ion or molecule, which is often $H^+$.

### 3.3.2 Active Transport Mechanism:

Larger or more-charged molecules have great difficulty in moving across a membrane, requiring active transport mechanisms (i.e., sugars, amino acids, DNA, ATP, ions, phosphate, proteins, etc.).

Active transport across a selectively permeable membrane occurs through ATP-powered pumps that transport ions against their concentration gradients. This mechanism utilises energy released by hydrolysis of ATP. The $Na^+$ - $K^+$ ATP pump transports $K^+$ into the cell and $Na^+$ out of the cell, another example is the $Ca^{2+}$ - ATP pump. Thus, it can be understood from the above discussion that the ion transport mechanisms operate both actively and passively. For some of the ions the uptake mechanism is active and for some others it is passive.

## 4.0 CONCLUSION

Mineral nutrients are elements acquired primarily in the form of inorganic ions from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense plants act as the "miners" of Earth's crust. The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution make mineral absorption by plants a very effective process.

After being absorbed by the roots, the mineral elements are translocated to the various parts of the plant, where they are utilised in numerous biological functions. Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with mots in the acquisition of nutrients.

**SELF-ASSESSTMENT EXERCISE (SAE)**

- Explain the Meaning of Mineral nutrition
- Outline the classification of essential elements into two groups
- Discuss the Criteria of essentiality of Mineral Elements
- Classification of plant nutrients based on their biochemical role and physiological function
- Briefly discuss the Mineral availability shows an interesting dose effect
- List the Specific roles of essential mineral elements
- Explain the Physiology of Nutrient Uptake

## 5.0 SUMMARY

The Meaning of Mineral nutrition and the criteria of essentiality of mineral elements classification of plant nutrients based on their biochemical role were discussed. Explain further was the physiological function mineral availability shows an interesting dose effect with specific roles of essential mineral elements and Physiology of Nutrient Uptake

## 6.0 TUTOR-MARKED ASSIGNMENT

1) Explain the Meaning of Mineral nutrition
2) Outline the classification of essential elements into two groups
3) Discuss the Criteria of essentiality of Mineral Elements
4) Classification of plant nutrients based on their biochemical role and physiological function
5) Briefly discuss the Mineral availability shows an interesting dose effect
6) List the Specific roles of essential mineral elements
7) Explain the Physiology of Nutrient Uptake

## 7.0 REFERENCES/FURTHER READING

C. Witt, R.J. Buresh, S. Peng , V. Balasubramanian , and A. Dobermann (2007). Nutrient Management. International Rice Research Institute (IRRI), Philippines

T.H. Fairhurst, C. Witt, R.J. Buresh, and A. Dobermann (eds). (2007). *Rice: A Practical Guide to Nutrient Management (2nd edition)*. International Rice Research Institute (IRRI), Philippines

# MODULE 5: PLANT GROWTH AND REGULATORS

## UNIT 1: Plant Growth Regulators



### 1.0 INTRODUCTION

The plant growth regulators are small, simple molecules of diverse chemical composition. They are organic substances synthesized in one part of the plant body and transported to another part where they are active. PGRs (Plant Growth Regulators) are also known as plant hormones or phytohormones.

They are the regulators produced by the plants which in low concentrations regulate the metabolic process. The PGRs can be broadly classified into two categories:

a) Growth promoters
b) Growth inhibitors, depending on their growth promoting or inhibiting activities respectively.

Generally five types of chemical growth regulating systems have been identified by plant physiologists namely

1. Auxins
2. Gibberellins or GAs
3. Cytokinins
4. Abscissic acid or ABA
5. Ethylene.

In this module PGRs (Auxin, Gibberellins, Cytokinins, Abscissic acid and Ethylene) of major importance are being described.

### 2.0 OBJECTIVES

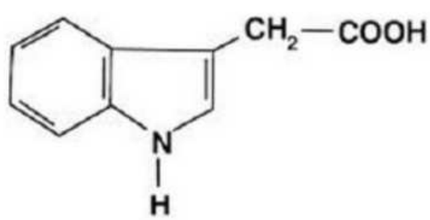
By the end of this unit, you should be able to:

- Understand general account of plant hormones
- Diagrammatic representation of different experiments regarding the discovery of Auxin
- Physiological effect of Auxin, Gibberellin, Cytokinin, Abscissic acid and Ethylene

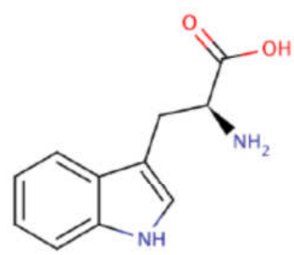
## 3.0 MAIN CONTENTS

### 3.1 Auxin

The term auxin is derived from the Greek word auxein which means to grow. Compounds are generally considered auxins if they can be characterized by their ability to induce cell elongation in stems and otherwise resemble Indole Acetic Acid (IAA, the first auxin isolated) in physiological activity.




indole-3-acetic acid
(IAA)




Tryptophan

Auxins usually affect other processes in addition to cell elongation of stem cells but this characteristic is considered critical of all auxins and thus "helps" define the hormone. Although there is only one naturally occurring auxin: indole-3-acetic acid (IAA: chemically related to the amino acid tryptophan), there are many synthetic auxins as we shall see in laboratory.

#### 3.1.1 Synthesis of Auxin

The most active auxin in plants is indole-3-acetic acid (IAA) and its most active areas of synthesis are in young leaves, fruits, flowers, shoot tips, embryos, and pollens. Some synthetic compounds have auxin like effects; such as 2, 4-D and NAA. 2, 4-D is used as a herbicide because it is relatively cheap and non-toxic (?) to humans (some question here relative to potential carcinogenicity). Other uses of synthetic auxins are that they are used to produce roots on cuttings, prevent pre-harvest dropping of fruits and prevent lateral buds from growing.

### 3.1.2 Effects of Auxin

**Apical dominance:** In higher plants the apical bud is far more active than the lateral buds. For certain period the growth of the lateral buds is suppressed. This phenomenon is called as apical dominance. According to Thimann and co-workers auxin is responsible for the dominance of apical bud. Apical dominance seems to result from the downward transport of auxin produced in the apical meristem. In fact, if the apical meristem is removed and IAA applied to the stumps, inhibition of lateral buds is maintained (Fig. 5.1).

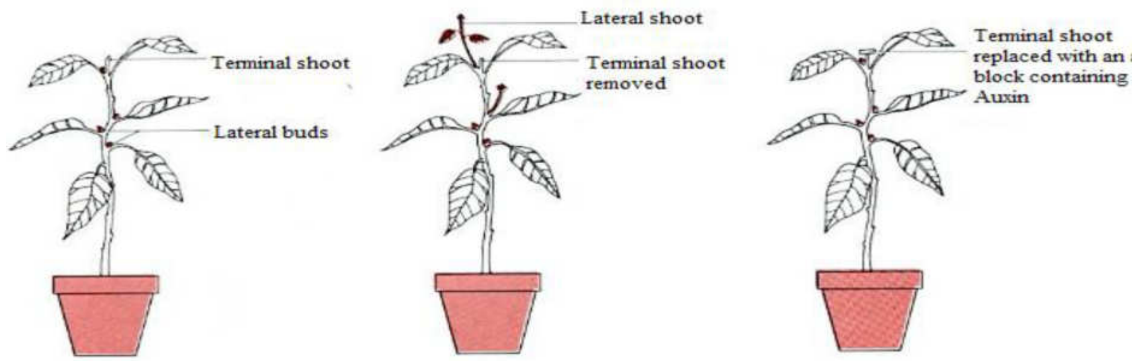
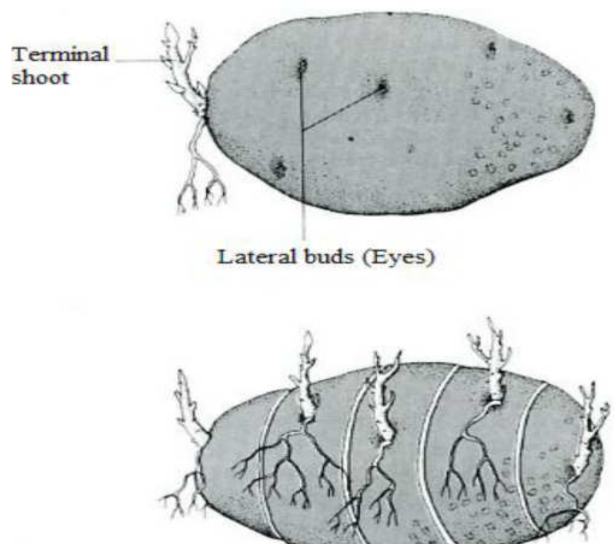



**Fig. 5.1: Experiment showing effect of Auxin**

The common white potato is really a portion of the underground stem of the potato plant. It has a terminal bud or "eye" and several lateral buds. After a long period of storage, the terminal bud usually sprouts but the other buds do not. However, if the potato is sliced into sections, one bud to a section, the lateral buds develop just as quickly as the terminal bud




(Fig. 5.2).

**Fig. 5.2: Showing emergence of lateral buds**

**Parthenocarpy:** As a result of pollination the auxin level of ovary is raised resulting in fruit formation, when the ovary is converted into fruit without occurrence of fertilization, the phenomenon is called as parthenocarpy. The auxins (IAA; IBA; NAA; NOAA; 2, 4-D; 2, 4, 5-T) are applied in low concentration (10-7- 10-6 M) in a lanolin paste to the stigma of the flower and, as a result parthenocarpy is induced.

**Root initiation:** The auxins induce rooting in stem cuttings. Application of IAA in low concentration at the cut end of stem induces formation of adventitious roots. Besides, IBA, NAA, and 2, 4-D are also successfully used for this purpose. This property of auxins is of great economic importance for multiplying plants by cutting in nurseries.

**Prevention from abscission**: Auxin also plays a role in the abscission of leaves and fruits. Young leaves and fruits produce auxin and so long as they do so, they remain attached to the stem. When the level of auxin declines, a special layer of cells - the abscission layer - forms at the base of the petiole or fruit stalk. Soon the petiole or fruit stalk breaks free at this point and the leaf or fruit falls to the ground.

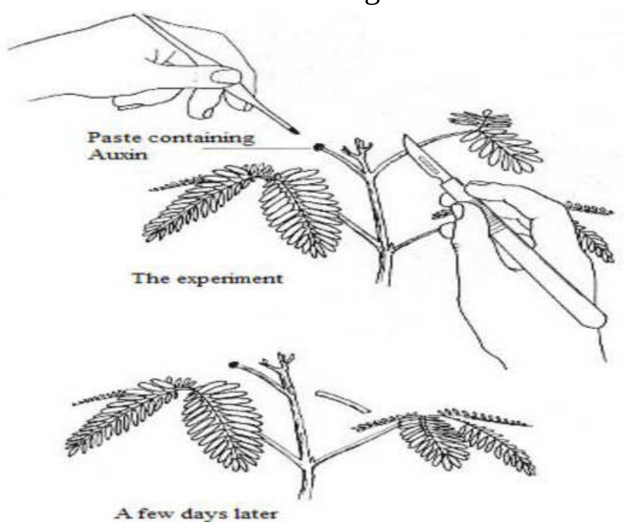



**Fig. 5.3: Showing prevention from senescence**

The Fig.5.3 shows a nice demonstration of the role of auxin in abscission. If the blade of the leaf is removed, as shown in the figure, the petiole remains attached to the stem for a few more days. The removal of the blade seems to be the trigger as an undamaged leaf at the same node of the stem remains on the plant much longer, in fact, the normal length of time. If, however, auxin is applied to the cut end of the petiole, abscission of the petiole is greatly delayed. Fruit growers often apply auxin sprays to cut down the loss of fruit from premature dropping (Fig. 5.4)

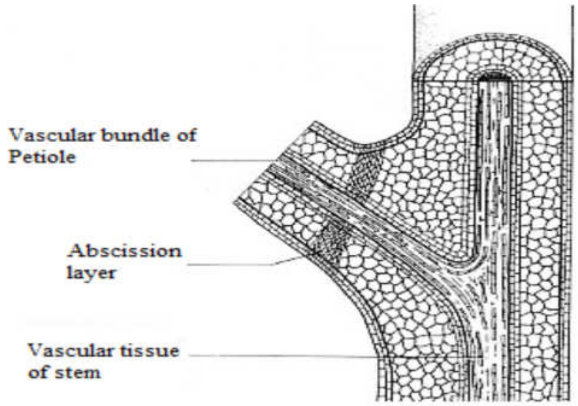



**Fig. 5.4: Petiole showing abscission layer**

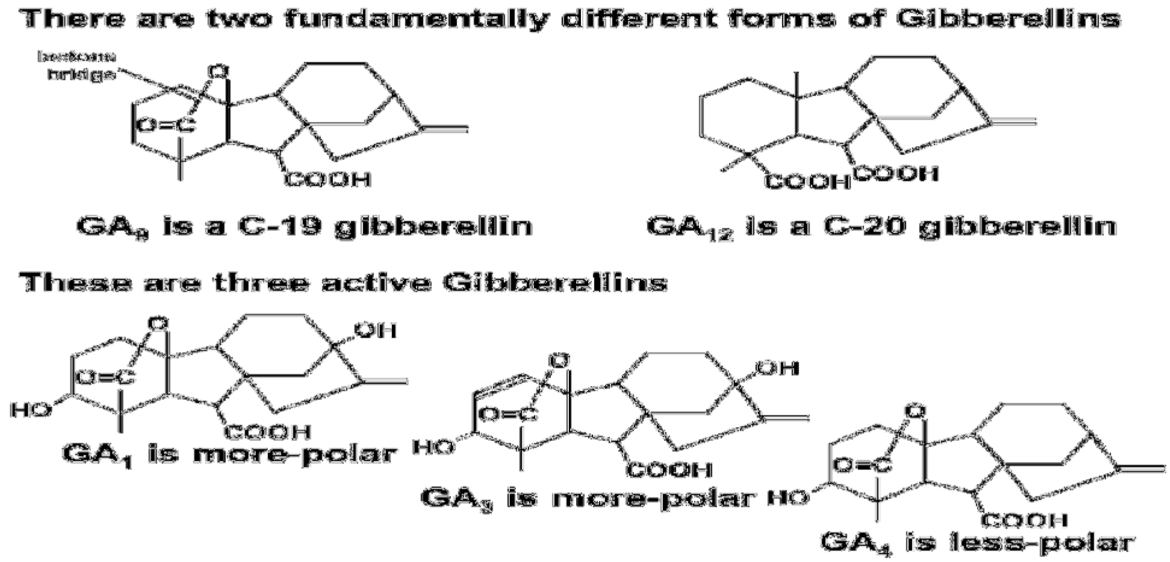
**Removal of weeds**: A concentration of auxins like 2, 4-D and 2, 4, 5-T destroys dicot weeds (not the monocot weeds). The roots are sensitive to auxins. They block their sieve elements and disturb mitosis. The plant is ultimately destroyed.

**Stimulation of respiration**: The auxins induce respiration, perhaps by providing more ADP to be converted to ATP.

The auxins also bring about shortening of internodes. This property of auxins is useful in apple where flowers and fruits are borne on dwarf shoots. By auxin sprays more dwarf shoots are formed.

### 3.2 Gibberellins

The gibberellins are present in all groups of plants i.e., from algae to Angiosperms but rarely in fungi and bacteria. They may be synthesized at places where they are needed or they may be transported from other regions. The transport is done by diffusion through xylem as also through phloem. Their transport is non-polar. The young leaves are the main sites of gibberellin synthesis. In contrast, the older leave shave only a little ability to do so. The gibberellin synthesis in young leaves renews the activity of the vascular cambium. The roots synthesize gibberellins in sufficient amount. If the roots are repeatedly excised, a marked decreased in the concentration of the gibberellins is observed in the shoot. This suggests that dicot the shoot's gibberellin is derived from the root's via xylem elements. The immature seed contain a higher percentage of gibberellin in comparison to mature seeds. This increased concentration is due to synthesis and not due to transport. In grass seeds the gibberellin synthesis mainly occurs in the scutellum and probably in others parts too.




### 3.2.1 Mechanism of action

It stimulates cell division in shoot tip. The cell growth is promoted by the increase in the hydrolysis of starch, fructose, and sucrose. It further well plasticity. Most of the workers are the opinion that the effect of gibberellin is indirect since they act by altering the auxin status. In the aleurone layer of barley the gibbrerllin increase the transcription of genes that code of protease and amylase enzymes. The protease activity produces tryptophan which is translocated to coleoptile tip where it is converted to IAA. The IAA shows polar movement.

### 3.2.2 Physiological effects

1. **Stem elongation**: The gibberellin induces internodal elongation. When treated with gibberellins, the lettuse plant became vine like.
2. **Light induced stem growth**: Dark grown etiolated plants are lean, tall, and yellow. Perhaps light has inhibiting effect on stem growth. It is thought that light induced inhibition of stem growth is overcome by exogenous application of gibberellins.
3. **Genetic dwarfism**: By the application of gibberellins, Lang (1956) observed a rapid growth or 'bolting' on some dwarf plant. Similar behavior has been observed in dwarf rice, maize, watermelon, squash, and cucumber.
4. **Promotion of flowering in long-day plants**: The long day plants generally possess a basal rosette of leaves. Before flowering they show significant internodal growth. After receiving the minimum hours of day light requirement, they bolt and flower. The continuation of rosette form or bolt and flower is linked with the amount of native gibberellins present in the plant.

5. **Increase in flower and fruit size**: By the exogenous application of gibberellin the size of flower of *Geranium* and *Camellia* increased. Similar application of gibberellin also increased the size of the fruit of *Vitis.*
6. **Parthenocarpy**: Like auxins, the exogenous application of gibberellins also induced the production of parthenocarpic fruits. They are also applied to the stigma in a lanolin paste.
7. **Substituting cold treatment**: By exogenous application of gibberellins, many biennials can be induced to behave as annuals and they no more require the natural chilling treatment for their flowering.
8. **Breaking of dormancy**: The exogenous application of gibberellins have been shown to be capable of breaking the dormancy of potato tubers and buds of trees in winter.

In addition to above, the gibberellins promote hypocotyl growth, increase in the number and size of leaves, expression of apical dominance, delay the senescence of leaves and *Citrus* fruits, sexual development of flowers particularly the maleness as well as the enzyme activity.

### 3.2.3 Commercial uses of Gibberellins

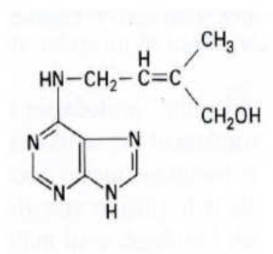
Commercially the gibberellins are employed in the following:

1. Increase in the size of Thompson seedless grape fruits as also the distance in between them.
2. Increase in the height of sugar cane plant and more sugar yield.
3. Increase in the fresh weight of pastures and hay crops.
4. In storage of oranges, gibberellin prevents rind disorder by delaying senescence.

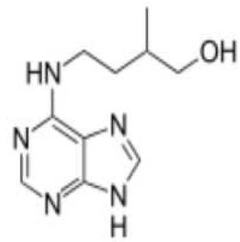
## 3.3 Cytokinin

Skoog *et al.* (1965) defined cytokinin as 'chemicals' which regardless of their activities promote cytokinesis in various plant organs'

The most common and physiologically active cytokinins are **zeatin**, **dihydrozeatin**, and **isopentanyl adenine**. Benzyladenine was regarded as a synthetic cytokinin but Ernst (1983) found 6-benzyladenine riboside in the seeds of *Pimpinella anisum*.




Structure of zeatin




Structure of dihydrozeatin

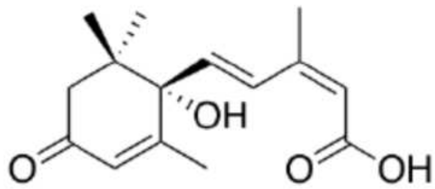
### 3.3.1 Biological activities

1. **Cell division:** The cytokinins induce cell division activity. It is the most characteristic property of cytokinin. By its application a normal cell of *Vinca* was converted to a tumor cell. They also induce cell division activity in bacteria such as *E. coli.*
2. **Cell elongation:** They induced cell enlargement. It was observed in disc etiolated leaves as well as tobacco pith and cortical cells. This property is enhanced in combination with auxins.
3. **Morphogenesis:** By applying cytokinin and IAA in balanced combination, tobacco pith cells produced callus. If the amount of cytokinin is increased, differentiation of buds was observed in the callus.
4. **Breaking dormancy:** The dormancy of seeds of *Lactuca sativa* is broken by a spray of cytokinin. It is thought that the site of cytokinin action on seed germination in the cotyledon.
5. **Supperesion of apical dominance:** The cytokinin counteract the phenomenon of apical dorminance. In fact this phenomenon is controlled by a balance of concentration between endogenous IAA and cytokinins.
6. **Delay in senescence:** Richmond and Lang (1967) observed that the degradation of proteins and chlorophyll was delayed in the detached leaves of *Xanthium*, if there was cytokinin in the medium. The phenomenon of delay in senescence by cytokinin treatment is also caused as **Richmond-Lang effect.**

## 3.4 Abscissic Acid

When a fruit ripens or before a leaf falls, a special zone of cells is formed at the base of the pedicel or petiole. This zone is called as **abscission zone**. It is delimited by a protection layer on the stem side and a **separation layer** on the organ side. The fruit or leaf is ultimately separated and the phenomenon is called as **abscission.**

### 3.4.1 Structure




**Structure of Abscissic acid**

The ABA is a terpenoid having an asymmetric carbon. It is a C-15 sesquiterpene (with 3 isoprene units). Most of the hormone is synthesized in leaves and fruits. Some of ABA in chloroplast can arise from xanthophyll, **violaxanthin.**

### 3.4.2 Physiological Effects of Abscissic Acid

1. **Seed and bud dormancy:** Abscissic acid induces dormancy of buds towards the approach of winter. Abscissic acid accumulates in many seeds during maturation and apparently contributes to seed dormancy.
2. **Senescence:** ABA acts as a general inducer of senescence. The onset of senescence is correlated with stomatal closure. The ABA content of aging leaves increases markedly as senescence is initiated.
3. **Flowering:** In long-day plants, the effect of gibberellins on flowering is counteracted by ABA, which accumulated in the leaves during the short winter days. This ABA acts as inhibitor of flowering in long-day plants. On the other hand ABA induces flowering in short-day plants.
4. **Starch hydrolysis:** The GA-induced synthesis of a-amylase and other hydrolytic enzymes in barley aleurone cells is inhibited by abscissic acid. This inhibition can be reversed by increasing the amount of GA supplied.

## 3.5 Ethylene

It was observed in 1864 that the gas illuminating the streets in German cities, due to leakage to pipes caused leaf fall in road side shade trees. This gas was thought to be responsible for causing senescence and abscission of leaves. The gas was identified as ethylene (CH2=CH2) in both the cases. Galston and Davis (1970) recognized it as a growth regulator.

### 3.5.1 Physiological Effects of Ethylene

1. Unripe fruits can be made to ripe before proper time if they are kept in ethylene atmosphere.
2. In some plants, it stimulates germination of seed.
3. It inhibits root and stem elongation but induces root hair formation.
4. It also induces cellulose activity leading to promotion of leaf abscission.
5. It induces petal discoloration.

**SELF ASSESSMENT EXERCISE**

- Give general account of plant hormones
- Explain with diagrams the different experiments regarding the discovery of Auxin
- Explain the physiological effect of Auxin, Gibberellin, Cytokinin, Abscissic acid and Ethylene

## 4.0 CONCLUSION

The plant growth regulators are small, simple molecules of diverse chemical composition. They are organic substances synthesized in one part of the plant body and transported to another part where they are active. PGRs (Plant Growth Regulators) are also known as plant hormones or phytohormones. They are the regulators produced by the plants which in low concentrations regulate the metabolic process. The PGRs can be broadly classified into two categories: Growth promoters, Growth inhibitors, depending on their growth promoting or inhibiting activities respectively. Generally five types of chemical growth regulating systems have been identified by plant physiologists namely, Auxins, Gibberellins or Gas, Cytokinins, Abscissic acid or ABA and Ethylene.

## 5.0 SUMMARY

The plant growth regulators are small, simple molecules of diverse chemical composition. They are organic substances synthesized in one part of the plant body and transported to another part where they are active. The term auxin is derived from the Greek word auxein which means to grow. Compounds are generally considered auxins if they can be characterized by their ability to induce cell elongation in stems. A concentration of auxins like 2, 4-D and 2, 4, 5-T destroys dicot weeds (not the monocot weeds). The immature seed contain a higher percentage of gibberellin in comparison to mature seeds. This increased concentration is due to synthesis and not due to transport. In grass seeds the gibberellin synthesis mainly occurs in the scutellum and probably in others parts too. The gibberellin induces internodal elongation. It is also effective in genetic dwarfism, promotion of flowering in long day plants, Increase in flower and fruit size, parthenocarpy and breaking of dormancy. The most common and physiologically active cytokinins are zeatin, dihydrozeatin, and isopentanyl adenine. Abscissic acid induces dormancy of buds towards the approach of winter. Abscissic acid accumulates in many seeds during maturation and apparently contributes to seed dormancy. ABA acts as a general inducer of senescence. It is also effective in flowering and starch hydrolysis. Ethylene gases are helpful for unripe fruits which can be made to ripe before proper time if they are kept in ethylene atmosphere.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Name natural auxin found in plants.
2. Write down the physiological effects of Auxins.
3. Suggest the most characteristics effect of gibberellins in plants.
4. Name the most common cytokinin reported in plants.
5. Name a hormone that is related with xylem differentiation.
6. Name the two synthetic auxins used for inducing the rooting in woody plants.

## 7.0 REFERENCES/FURTHER READING

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## UNIT 2: PLANT GROWTH

**CONTENTS**



### 1.0 INTRODUCTION

Plant cell growth is defined here in the broad sense as the initiation, expansion, and specialization of cells. The haploid spore or diploid zygote of land plants initially undergoes more or less continuous, sequential mitotic cell divisions. Later, as gametophytes or sporophytes mature, active cell divisions become restricted to certain regions of the plant. This region of actively dividing cells is known as a meristem. In the vascular plants apical meristems are located at the apices of roots and shoots, resulting in growth in height or length. Apical meristems may contain a single, enlarged apical initial cell (found in Selaginellaceae and monilophytes) or a group of actively dividing cells (known as *complex*, found in Lycopodiaceae, Isoetaceae, and seed plants). In woody seed plants both apical meristems and lateral meristems occur. Lateral meristems are cylindrical sheaths of cells, which function in growth that increases width or girth.

### 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Understand general concept of plant growth
- Differentiate between cell differentiation and its processes

### 3.0 MAIN CONTENTS

### 3.1 Plant Growth

Growth in plants occurs as the stems and roots lengthen. Some plants, especially those that are woody, also increase in thickness during their life span. The increase in length of the shoot and the root is referred to as primary growth, and is the result of cell division in the shoot apical meristem. In both apical and lateral meristems a single meristematic cell undergoes a mitotic cell division, giving rise to two cells. Each of these two “daughter cells” undergoes some initial expansion. The derivatives themselves may continue to divide several more times, but only those cells that remain near the meristem will do so indefinitely. The others eventually cease mitosis and undergo further differentiation (Figure 5.5).

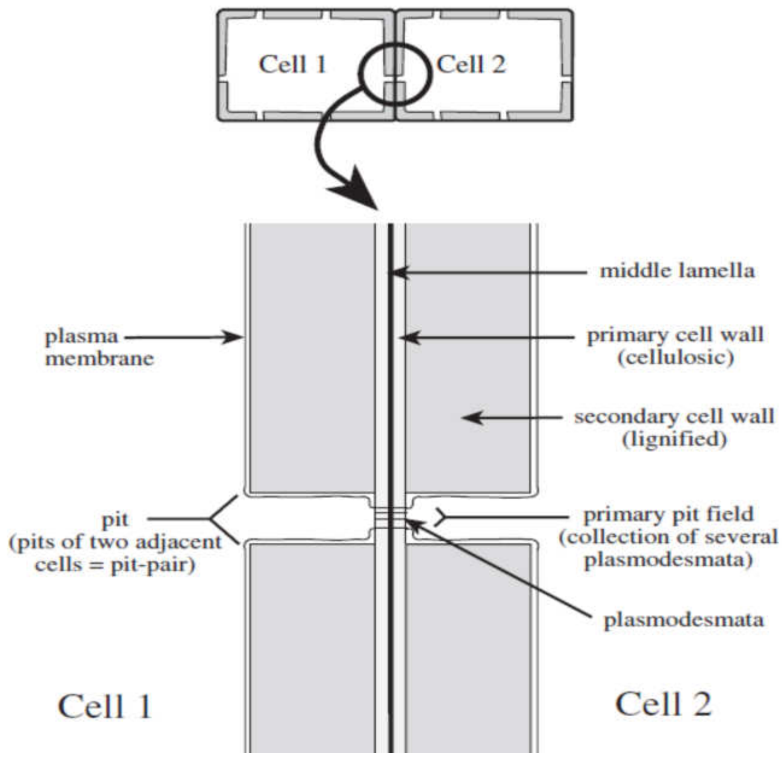


**Figure 5.5: Lignified secondary cell wall of specialized cells of vascular plants.**

Cell differentiation refers to the series of changes that a cell undergoes from the point of inception to maturity, involving the transformation of a meristematic cell into one that assumes a particular structure and function. Differentiation involves two processes:

- Cell expansion, in which the cell grows in size (often by elongation, in which growth in the axial direction is greatest); and
- Maturation or specialization, in which the cell acquires the structural and functional features at maturity. Cell specialization means simply that cells may differ from one another, becoming

specialized for a particular structure and function within the whole plant.

Cell differentiation results in the development of various cell types.

A tissue is a group of cells having a common function or structure. Plant tissues of the vascular plants are often categorized into three broad classes: ground, vascular, and dermal; see later discussion. In addition, tissues may be classified as simple or complex. A simple tissue consists of only one type of cell; thus, a particular term may refer either to the simple tissue or the cell type. A complex tissue contains more than one cell type.

**SELF ASSESSMENT EXERCISE**

- What is your understanding of the concept of plant growth
- Differentiate between cell differentiation and its processes

## 4.0 CONCLUSION

Growth in plants occurs as the stems and roots lengthen. Some plants, especially those that are woody, also increase in thickness during their life span. The increase in length of the shoot and the root is referred to as primary growth, and is the result of cell division in the shoot apical meristem.

## 5.0 SUMMARY

Genetic potential of a plant and its interaction with environmental factors decides its growth and development by influencing or modifying certain internal processes. Plant physiology studies about these internal processes and their functional aspects.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss plant growth
2. What is cell differentiation
3. List and explain the process of cell differentiation

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# MODULE 6: PLANT FUNCTIONS



## UNIT 1: PHOTOSYNTHESIS

**CONTENTS**



## 1.0 INTRODUCTION

Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that, through cellular respiration, can later be released to fuel the organism's metabolic activities. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesised from carbon dioxide and water – hence the name photosynthesis, from the Greek phos (φῶς), "light", and sun thesis (σύνθεσις), "putting together". In most cases, oxygen is also released as a waste product. Most plants, algae, and cyanobacteria perform photosynthesis; such organisms are called photoautotrophs. Photosynthesis is largely responsible for producing and maintaining the oxygen content of the Earth's atmosphere, and supplies most of the energy necessary for life on Earth.

Although photosynthesis is performed differently by different species, the process always begins when energy from light is absorbed by proteins called reaction centres that contain green chlorophyll pigments. In plants, these proteins are held inside organelles called chloroplasts, which are most abundant in leaf cells, while in bacteria they are embedded in the plasma membrane. In these light-dependent reactions, some energy is used to strip electrons from suitable substances, such as water, producing oxygen gas. The hydrogen freed by the splitting of water is used in the creation of two further compounds that serve as short-term stores of energy, enabling its transfer to drive other reactions: these compounds are reduced nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP), the "energy currency" of cells.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to;

- Explain the Meaning and Definition of Photosynthesis
- Give Meaning of Photochemical Reaction
- Understand the Biochemical Step

## 3.0 MAIN CONTENTS

### 3.1 Photosynthesis

All life forms on earth require energy for maintenance, growth, and productivity. This energy is derived directly or indirectly from the sun for most organisms, and the first step in the use of solar energy is the process of photosynthesis.

Photosynthesis can be defined as the synthesis of organic compounds (primarily sugars) from carbon dioxide ($CO_2$) and water using light energy. It can also be defined as the process by which light energy from the sun is converted into chemical energy of carbohydrate molecules. The main products of photosynthesis are carbohydrates (of general chemical formula $C_6H_{12}O_6$) and oxygen gas ($O_2$). A summary of the overall process is as follows:

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

Photosynthesis is the most important characteristic of plants, and all agriculture is dependent on this process directly or indirectly. There are three major steps in the process of photosynthesis:

1. The $CO_2$ diffusion step,
2. The Photochemical step, and

3. The Biochemical step.

In the diffusion step, $CO_2$ diffuses from the air (which has about 0.04% $CO_2$) into the plant tissue to the site of photosynthesis (chloroplasts). There is first a vapor phase diffusion of $CO_2$ largely through the stomata to the intercellular spaces, followed by liquid phase diffusion to the chloroplasts. We will now examine with greater detail the photochemical and biochemical steps of photosynthesis.

## 3.2 The Photochemical Step

The photochemical step of photosynthesis consists of what are called light-dependent reactions that occur within the chloroplasts. During this step, light energy is absorbed by pigments within the chloroplast and used to produce a high energy compound (adenosine triphosphate, ATP) and a strong reducing agent (reduced nicotinamide adenine dinucleotide phosphate, NADPH). The water molecule is also split during this step and oxygen is released.

### 3.2.1 Chloroplasts

A leaf cell may contain 40-50 chloroplasts, and there may be hundreds of thousands of chloroplasts per square millimeter of leaf surface. The chloroplast is surrounded by a double membrane and contains a dense solution called stroma. Within the stroma another membrane system forms flattened sacs or vesicles called thylakoids. The green chlorophyll pigments and other pigments are located on the thylakoid membranes. Groups of thylakoids are often stacked together on the flat surfaces to form grana (singular = granum). Within the thylakoids there is a lumen filled with a solution that is different from the outside stroma.

### 3.2.2 Photosystems

On the thylakoid membranes, certain pigments and associated proteins are packed together to form units called photosystems.

There are two types of photosystems, designated Photosystem I (or PSI) and Photosystem II (or PSII). Each photosystem has a critical pigment for photosynthesis (called chlorophyll a) and accessory pigments, e.g., chlorophyll b and carotenoids. The critical chlorophyll a pigment is designated P700 for PSI and P680 for PSII, indicating the light wavelength that is absorbed most efficiently by these pigments. The chlorophyll pigments absorb mainly red and blue light wavelengths, and reflect and transmit green wavelengths, so leaves are green. The accessory pigments absorb light of slightly different wavelengths than chlorophyll a, and channel this energy to chlorophyll a. In higher plants, both photosystems must cooperate in carrying out photosynthesis.

### 3.2.3 The Photosynthetic Z-Scheme

To understand the light-dependent reactions of photosynthesis, it is best to start with reactions in PSII. Light energy is trapped by PSII causing an electron from P680 to be promoted to a higher energy level (an excited state). This excited electron is rapidly transferred to a primary electron-acceptor molecule that is closely associated with P680. If this transfer does not occur immediately, the excited electron falls back to its ground state in P680, giving-off energy (fluorescence) in the process. From the primary electron acceptor, the electron is transferred from one acceptor to another within PSII. In this electron transfer chain, the energy of the excited electron is utilized to move protons (H1) from the stroma to the lumen of the thylakoids. Finally, a mobile electron acceptor carries the electron to PSI where it is transferred to P700. The photochemical reactions can be illustrated in the Photosynthetic Z-scheme (Fig. 6.1).

As electrons move on to Photosystem I, the pigment P680 (in Photosystem II) is depleted of electrons and becomes a powerful oxidizing agent capable of stripping electrons from water, thereby splitting the water molecule as follows:

$$2H_2O \longrightarrow 4H^+ + 4e^- + O_2$$

Protons released from this reaction accumulate in the lumen of the thylakoids. P700 (in PSI) also absorbs light energy and in so doing one electron (supplied by PSII) is promoted to the excited state. Again this excited electron is immediately transferred to a primary electron acceptor closely associated with PSI.

From the primary electron acceptor, the excited electron moves across an electron transfer chain and is finally transferred to NADP1 resulting in the formation of NADPH as follows:

$$NADP^+ + 2e + H^+ \longrightarrow NADPH$$

This reaction occurs on the stroma side of the thylakoid membrane. NADPH is a powerful reducing agent, which means that it has a strong ability to force its electrons and hydrogen on to other molecules.

### 3.2.4 Photophosphorylation

The above reactions result in the accumulation of protons ($H^+$) in the lumen of the thylakoids and a depletion in the stroma, which leads to a large gradient in proton concentration across the thylakoid membranes. Protons flow out to the stroma through specialized membrane proteins (called ATP synthase) that utilize the energy of this electrical flow to synthesize ATP from adenosine diphosphate (ADP) and inorganic phosphate (Pi) as follows:

$$ADP + Pi + energy \rightarrow ATP$$

The plant can utilize energy stored in the triple bond of ATP at a later time for any type of activity that requires energy. Therefore, ATP serves as energy currency in the plant. The entire process that utilizes light energy to produce high-energy phosphate bonds is referred to as photophosphorylation.

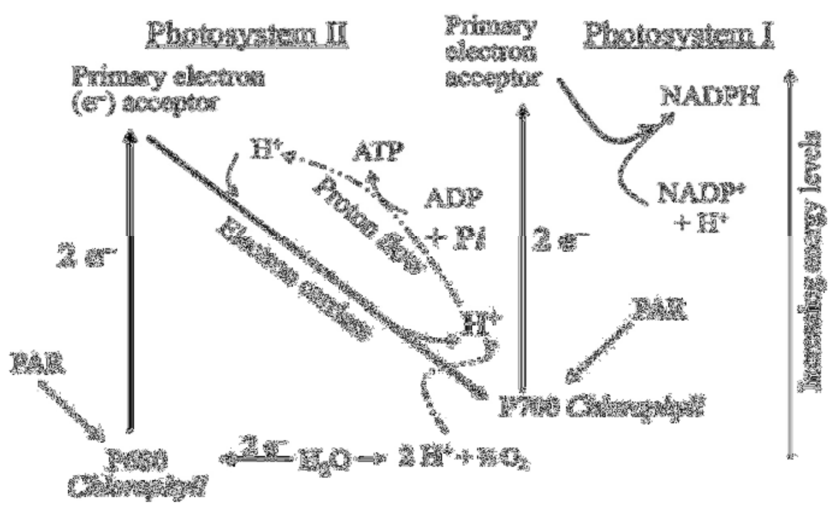


**Figure 6.1: Diagrammatic representation of the photochemical reactions (the Photosynthetic Z-scheme)**

### 3.3 The Biochemical Step

The biochemical step of photosynthesis consists of what are called light-independent reactions that can occur in darkness. During the biochemical step of photosynthesis, the products of the photochemical step (ATP and NADPH) are used to incorporate carbon dioxide into organic compounds.

The energy of solar radiation becomes stored in these organic molecules as energy associated with chemical bonds. During respiration, organic molecules are broken down to release $CO_2$ and the stored energy is made available for various activities.

### 3.3.1 The Calvin Cycle and C3 Plants

The light-independent reactions can proceed once products (NADPH and ATP) of the light-dependent reactions are present in the chloroplast. The actual fixation of carbon dioxide, which diffuses into the leaf from the atmosphere, occurs by a cyclic series of reactions called the Calvin cycle (named after one of the pioneer researchers in this area). A summary of the Calvin cycle is illustrated in Fig. 6.2.

There are three major steps in the Calvin cycle: Carboxylation, reduction, and regeneration. The initial incorporation of $CO_2$ (carboxylation step) is catalyzed by an enzyme called rubisco (ribulose bisphosphate carboxylase-oxygenase) which occurs in relatively large quantities in photosynthetic tissues. In this reaction, $CO_2$ (a molecule containing one carbon atom) combines with a five-carbon compound (ribulose bisphosphate, or RuBP) to form an unstable product that immediately breaks down to give two molecules of a three-carbon compound (phosphoglyceric acid or PGA).

RuBP (5 – carbon) + $CO_2$ (1 – carbon)   2 molecules of PGA (3 – carbon)

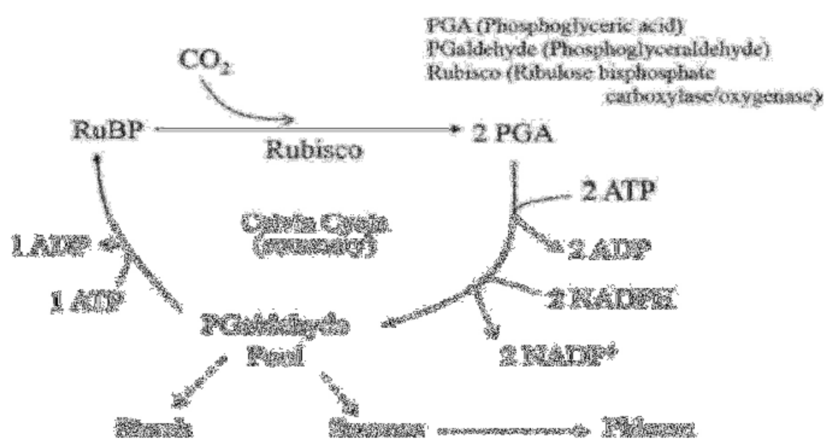


**Figure 6.2: Summary reactions of the photosynthetic biochemical step.**

Plants in which the first detectable product of photosynthesis is a three-carbon compound are called C3 plants (Fig. 6.3). Energy of ATP and the reducing power of NADPH are then used to reduce PGA to phosphoglyceraldehyde (PGaldehyde) in the Reduction step. ATP is also needed in the Regeneration step to regenerate molecules of the original five-carbon compound (RuBP) from molecules of the three-carbon compound (PGaldehyde).

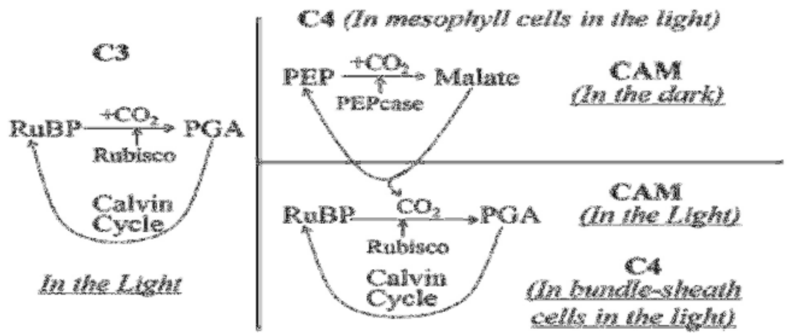


**Figure 6.3: Photosynthetic biochemical pathways in C3, C4, and CAM plants.**

### 3.3.2 Photorespiration

Photorespiration can be defined as the evolution of $CO_2$ during photosynthesis. It arises because rubisco can act as either a carboxylase (incorporating $CO_2$) or as an oxygenase (incorporating $O_2$). In the presence of relatively high $CO_2$ levels, rubisco acts mainly as a carboxylase. However, when oxygen levels are high, rubisco acts as an oxygenase and incorporates $O_2$ into the five-carbon compound (RuBP) as follows:

RuBP (5 - carbon) + $O_2$ $\rightarrow$ PGA (3 – carbon) + glycolate (2 – carbon)

The PGA formed continues along the Calvin cycle, while glycolate is metabolized in the glycolate pathway involving chloroplasts and other cell organelles. In the glycolate pathway there is a net loss of $CO_2$, and ATP and NADPH are required. Therefore, photorespiration appears to be a very wasteful process in which net $CO_2$ fixation is reduced and energy is also used up in the process. Any factor that reduces the availability of $CO_2$ or increases the availability of $O_2$ to rubisco will increase the levels of photorespiration.

### 3.3.3 C4 Plants

Under hot dry conditions, stomata tend to close which serves to restrict water loss. However, stomatal closure restricts the diffusion of $CO_2$ to the chloroplasts and $O_2$ levels also build up, which encourages photorespiration. Some plants have evolved mechanisms to reduce the levels of photorespiration under these conditions. In many of these plants two enzymes are involved in the incorporation of $CO_2$.

In some plants the first detectable product of photosynthesis is not a three-carbon compound but a four-carbon compound. These plants are called C4 plants, and in addition to rubisco they have another enzyme (phophoenolpyruvate carboxylase, or PEPcase) capable of capturing $CO_2$. PEPcase is present in the mesophyll cells of the leaf, while rubisco occurs only in cells (called bundle sheath cells) immediately surrounding the transport tissue (vascular bundles).

PEPcase first incorporates $CO_2$ into a three-carbon compound (phosphoenolpyruvate, or PEP) to form a four-carbon compound (oxaloacetic acid, OAA). OAA is not very stable and is quickly converted to either malic acid or aspartic acid (four-carbon compounds).

The four-carbon compound formed from the activity of PEPcase diffuses to the bundle sheath chloroplasts, where the newly fixed $CO_2$ is released for incorporation by rubisco in the Calvin cycle. After releasing $CO_2$, the resulting three carbon compound returns to the mesophyll cells and the process is repeated. However, some additional energy (ATP) is required for PEP to be regenerated. The C4 mechanism serves to concentrate $CO_2$ into the bundle sheath chloroplasts, thereby reducing the levels of photorespiration. Therefore, photorespiration tends to be negligible in C4 plants.

### 3.3.4 Crassulacean Acid Metabolism Plants

In some plants adapted to very dry (desert) conditions, the stomata are closed during the daytime and open at night. These plants are said to show the crassulacean acid metabolism (CAM) pathway, which was first discovered in members of the plant family Crassulaceae. Photosynthetic tissue of these plants contains both PEPcase and rubisco. During the night, when stomata are open, $CO_2$ is fixed by PEPcase to form malic acid, which accumulates in plant tissues.

During the day, stomata close and malic acid breaks down to release the fixed $CO_2$, this is then incorporated by rubisco in the Calvin cycle. Rubisco is activated by light, and has a lower affinity for $CO_2$ than PEPcase. A relatively high $CO_2$ concentration is likely to exist within the photosynthetic tissue when rubisco is active, so that photorespiration is generally lower than that of C3 plants.

### 3.3.5 Blackman's Law of Limiting Factors

Several environmental factors influence photosynthesis, and the actual rate of photosynthesis at any instant will be limited by the factor that is either in short supply or furthest from its optimum value. This is known as Blackman's Law of limiting factors (or Liebig's law of the minimum), which can be restated as follows:

*When a chemical process depends on more than one essential condition being favorable, its rate is limited by that factor that is nearest to its minimum value.*

For example, photosynthesis is likely to be limited by light under heavy shade conditions and according to Blackman's law cannot be increased by changes in any other factor besides light e.g., temperature, water supply, or carbon dioxide concentration. When light levels are increased to the photosynthetic light saturation point, another factor becomes the limiting factor. A good analogy to help explain Blackman's law is a barrel containing holes at different points on the sidewalls. The maximum height to which water can rise in the barrel is determined by the height of the hole nearest to the base of the barrel.

**SELF-ASSESSTMENT EXERCISE (SAE)**

1. Explain the meaning and definition of photosynthesis
2. Give meaning of photochemical step
3. Give meaning of biochemical reaction/step
4. What is your understanding of Blackman's Law of Limiting Factors

## 4.0 CONCLUSION

Photosynthesis can be defined as the synthesis of organic compounds (primarily sugars) from carbon dioxide ($CO_2$) and water using light energy. It can also be defined as the process by which light energy from the sun is converted into chemical energy of carbohydrate molecules. The main products of photosynthesis are carbohydrates (of general chemical formula $C_6H_{12}O_6$) and oxygen gas ($O_2$). Photosynthesis is the most important characteristic of plants, and all agriculture is dependent on this process directly or indirectly. There are three major steps in the process of photosynthesis: The $CO_2$ diffusion step; The Photochemical step, and The Biochemical step.

## 5.0 SUMMARY

The unit showed the meaning and definition of photosynthesis and its steps/reactions. It also explained the meaning of C02 diffusion step, the photochemical step and biochemical steps in photosynthesis the concept of cyclic photophosphorylation, the factors limiting photosynthesis.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning and definition of photosynthesis
2. List the three major steps/reactions of photosynthesis and explain each
3. Explain the concept of photorespiration
4. Outline the Concept of photophosphorylation
5. Outline the major differences between the C3, C4, and CAM photosynthetic pathways.

## 7.0 REFERENCES/FURTHER READING

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## UNIT 2: TRANSLOCATION

**CONTENTS**



### 1.0 INTRODUCTION

Translocation is the movement of materials from leaves to other tissues throughout the plant. Plants produce carbohydrates (sugars) in their leaves by photosynthesis, but nonphotosynthetic parts of the plant also require carbohydrates and other organic and nonorganic materials. For this reason, nutrients are translocated from sources (regions of excess carbohydrates, primarily mature leaves) to sinks (regions where the carbohydrate is needed). Some important sinks are roots, flowers, fruits, stems, and developing leaves. Leaves are particularly interesting in this regard because they are sinks when they are young and become sources later, when they are about half grown.

Photosynthates, such as sucrose, are produced in the mesophyll cells of photosynthesizing leaves. From there they are translocated through the phloem to where they are used or stored. Mesophyll cells are connected by cytoplasmic channels called plasmodesmata. Photosynthates move through these channels to reach phloem sieve-tube elements (STEs) in the vascular bundles. From the mesophyll cells, the photosynthates are loaded into the phloem STEs. The sucrose is actively transported against its concentration gradient (a process requiring ATP) into the phloem cells using the electrochemical potential of the proton gradient. This is coupled to the uptake of sucrose with a carrier protein called the sucrose-$H^+$ symporter.

Phloem STEs have reduced cytoplasmic contents, and are connected by a sieve plate with pores that allow for pressure-driven bulk flow, or

translocation, of phloem sap. Companion cells are associated with STEs. They assist with metabolic activities and produce energy for the STEs.
Once in the phloem, the photosynthates are translocated to the closest sink. Phloem sap is an aqueous solution that contains up to 30 percent sugar, minerals, amino acids, and plant growth regulators. The high percentage of sugar decreases Ψs, which decreases the total water potential and causes water to move by osmosis from the adjacent xylem into the phloem tubes, thereby increasing pressure. This increase in total water potential causes the bulk flow of phloem from source to sink. Sucrose concentration in the sink cells is lower than in the phloem STEs because the sink sucrose has been metabolized for growth, or converted to starch for storage or other polymers, such as cellulose, for structural integrity. Unloading at the sink end of the phloem tube occurs by either diffusion or active transport of sucrose molecules from an area of high concentration to one of low concentration. Water diffuses from the phloem by osmosis and is then transpired or recycled via the xylem back into the phloem sap.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to;

- Explain the Meaning and Definition of Translocation
- Understand translocation mechanism

## 3.0 MAIN CONTENTS

### 3.1 Translocation

The transport of products of photosynthesis (also called assimilates or photosynthates) from Source to Sink in plants is called translocation. The Source is a net exporter of assimilates (e.g., leaves), while the Sink is a net importer of assimilates (e.g., tubers, fruits, roots, stems). A storage tissue can become a Source when stored material is mobilized and exported.

#### 3.1.1 Translocation Mechanism

Translocation occurs in phloem tissue via sieve elements (with associated companion cells) and metabolic energy is required for this process. Rates of movement in the phloem can sometimes exceed 1 m per hour and substances can move in different directions at the same time. Movement by diffusion is much too slow to account for such rapid rates of movement observed in the phloem. Some movement in individual sieve elements may be explained by cytoplasmic streaming—this is a rotational movement of the cytoplasm around the periphery of many cells due to the action of microfilaments. Cytoplasmic streaming is readily observed in young but not in mature sieve elements, and observed rates of movement are still too slow to explain the rapid rates of movement that can occur in phloem tissue.

### 3.1.2 Munch's Pressure-Flow Theory

The most widely accepted explanation of the translocation mechanism is given by Munch's Pressure-Flow theory. This theory suggests that movement in the phloem is due to mass flow along a turgor (hydrostatic) pressure gradient.

Assimilates enter the sieve tubes of the phloem by active transport (phloem loading) at the Source (e.g., leaf). The osmotic potential falls as solutes accumulate in the sieve elements at the Source. Water is then dragged in by osmosis from surrounding tissue and ultimately from the xylem. The pressure increases as water enters the sieve tube leading to the mass flow of water and dissolved substances along the sieve tube under a hydrostatic pressure gradient.

Assimilates are removed from the sieve tubes (unloading) at a Sink (where assimilates are utilized). The water potential of the solution in the sieve tube increases as dissolved substances move out and the solution becomes more dilute. Water moves out when the water potential of the solution in the sieve tube becomes higher than that of the surrounding cells. This leads to a fall in the hydrostatic pressure at that location in the sieve tube, which serves to bring more phloem sap toward the active Sink. Water flowing out of the sieve tubes at the Sink will ultimately return to the xylem. Translocation is therefore linked to water flow in xylem (Fig. 6.4).

There are two mechanisms that can prevent uncontrolled loss of phloem sap in cases where the sieve tube is damaged:

1. Formation of P-protein (phloem protein) plugs. P-protein filaments form a fine network next to the plasma membrane of sieve elements. If the sieve tube becomes damaged, the P-protein (along with other contents of the phloem) surges toward the cut end due to the internal hydrostatic pressure. The tangled mass of protein filaments and protein bodies form a "P-protein" plug, which helps to seal the cut end of the sieve tube. However, not all flowering plants have P-proteins.
2. Proliferation of callose. This is a carbohydrate polymer that is synthesized by the plasma membrane especially under stress conditions. Callose is deposited into the tangled mass in the sieve pores of damaged sieve tubes, which serves to seal off the damaged sieve elements. Callose proliferates when there is a pressure drop, which helps to seal the sieve pores.

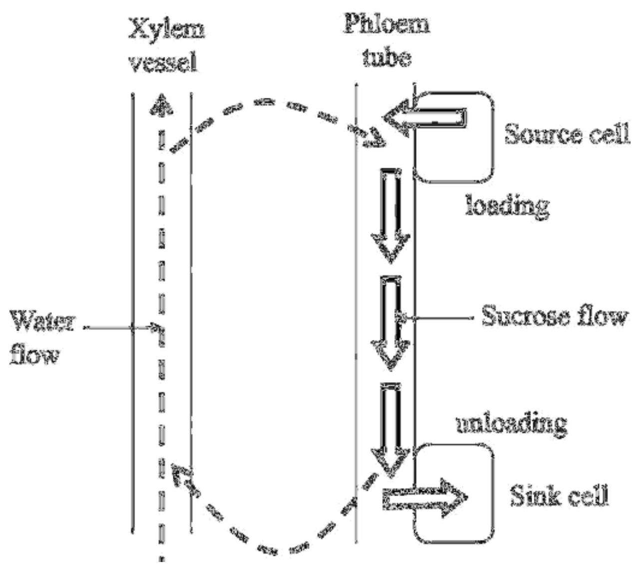


**Figure 6.4: Diagram illustrating the Pressure-Flow theory**

**SELF-ASSESSTMENT EXERCISE (SAE)**

1. Explain the mechanism of translocation
2. State the two mechanisms that can prevent uncontrolled loss of phloem sap in cases where the sieve tube is damaged

## 4.0 CONCLUSION

In plants, food is prepared by the leaves by the process of photosynthesis. The food prepared by the leaves is in the form of simple sugars (glucose).

No other part of the plant can prepare food. So, all the parts of a plant require food for getting energy, maintenance and growth. That is why; the food prepared by the leaves is transported to all the other parts of a plant through phloem. The transportation of food from the leaves to other parts of the plant is called translocation. The food made by the leaves of the plant is necessary to be translocated to all the other parts of the plant so that every part of the plant can utilize the food for obtaining energy as well as for growth and repair.

## 5.0 SUMMARY

In summary, translocation is the process within plants that functions to deliver nutrients and other molecules over long distances throughout the organism. Translocation occurs within a series of cells known as the phloem pathway, or phloem transport system, with phloem being the principal food-conducting tissue in vascular plants. Nutrients are translocated in the phloem as solutes in a solution called phloem sap. The predominant nutrients translocated are sugars, amino acids, and minerals, with sugar being the most concentrated solute in the phloem sap. Various cell types utilize these nutrients to support their requirements for life or store them for future use. Because translocation is responsible for the delivery of nutrients to developing seeds and fruits, this process is critical to the achievement of optimal crop yield.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Describe transport of food in plants
2. Define translocation? Why translocation is necessary for plants?
3. What do you mean by ‘translocation’ with respect to transport in plants?

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**UNIT 3 TRANSPIRATION**

**CONTENTS**



## 1.0 INTRODUCTION

Living plant tissues can contain about 95% water, and apart from being an essential constituent for life, water also has several specific roles in the plant. Water is a very good solvent and dissolves many organic and inorganic solutes, which facilitates the transportation of these substances around the plant. Certain properties of water molecules are beneficial for the buffering of temperature changes in plants, allowing plants to operate under more stable temperature conditions.

Hydrostatic pressure in plant tissue (due to water content) is very important for plant form, movement, leaf display, and growth. Water also takes part in many chemical reactions within the plant, such as hydrolysis reactions and photosynthesis.

However, most (98%) of the water that enters plant roots is lost by evaporation from the shoot system. The evaporative loss of water from plants is called transpiration, and this process is important for transport of substances within the plant as well as for evaporative cooling of leaves. We will now look at the pathways for water movement from the soil through the plant to the atmosphere and the forces that drive water flow.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to;

- Explain the Meaning and Definition of Transpiration
- Understand environmental factors affecting transpiration rates
- Distinguish between root pressure and transpiration pull

## 3.0 MAIN CONTENTS

## 3.1 Transpiration

Transpiration is a process that involves loss of water vapour through the stomata of plants. The loss of water vapour from the plant cools the plant down when the weather is very hot, and water from the stem and roots moves upwards or is 'pulled' into the leaves. When less water is available for the plants, dehydrated mesophyll cells release the plant hormone abscisic acid, which causes the stomatal pores to close and reduce the loss of water during release of oxygen and intake of carbon dioxide. Fig. 6.5 (a) shows the transpiration effect in plants with open and closed stomata.

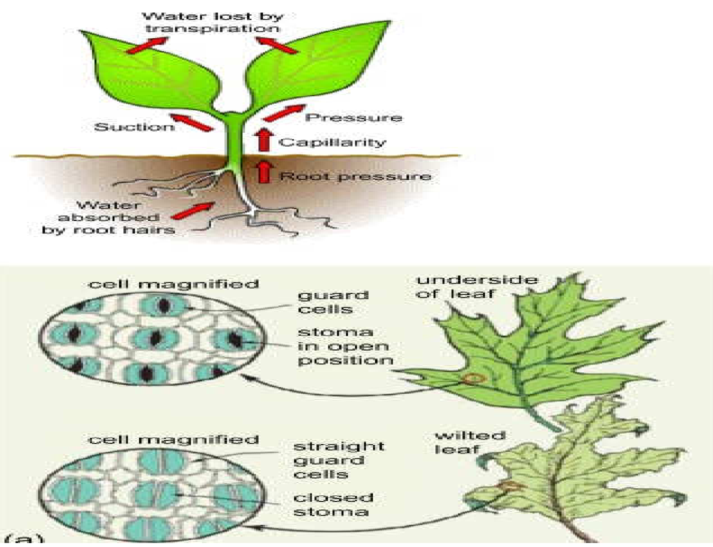


**Fig. 6.5: Transpiration effect in plants**

### 3.1.1 The Soil-Plant Atmosphere Continuum (SPAC) and Water Potential

There is a continuous pathway (called the SPAC) for the movement of water from the soil through the plant to the atmosphere. Water is present in a continuous system in the SPAC, and water movement in this system can occur by two major processes:

a) Diffusion—the net movement of a substance from one point to another due to the random (or thermal) motion of individual ions or molecules.
b) Mass flow—the simultaneous movement of groups of ions or molecules in one direction due to a hydrostatic pressure gradient.

In plants, mass flow occurs in the vascular tissue (e.g., xylem vessels) as a result of pressure gradients created by the diffusion of water into roots or out of leaves. What is the driving force for water movement by diffusion? To answer this question, we need to introduce the concept of water potential. Water potential of any system is a measure of the capacity of that system to give out water. The word "system" here can refer to a cell, solution, soil, atmosphere, or any part of the SPAC. Water moves spontaneously from a point of high water potential to one of low water potential in any system or across systems, once there is a pathway for water movement. The symbol commonly used to denote water potential is "Ψ" (the Greek letter "Psi").

Water potential is actually a measure of the free energy of water in the system, and free energy can be defined as the energy available to do work. However, absolute values of free energy are very difficult to determine and it is much easier to calculate relative values. Water potential is defined as the difference in free energy of water at any point in a system and that of pure unconfined water at the same temperature. Therefore, the free energy of water in any system is determined relative to that of pure water, which is assigned a water potential of zero as a consequence of our definition.

Water potential has units of pressure and is commonly expressed as MPa (Megapascals). Water potential has components due to the effects of dissolved substances, surfaces that attract water, hydrostatic pressure and gravity. There is usually a gradient in the water potential across the SPAC with values being high in the soil (-0.01 to -1.5 MPa) and low in the atmosphere (-10 to -200 MPa). This gradient in water potential provides tremendous driving force for water movement in the SPAC.

### 3.1.2 Water Uptake from Soil

Water is not held very strongly in the large pore spaces of the soil due to the reduced matric potential forces as the diameter of the pore spaces increases. Water in the largest pore spaces drains away readily under the influence of gravity, and this water is not available to plants. As plants take up water from the soil, water is first removed from the largest pore spaces that contain water. The water menisci then recede to smaller and smaller pore spaces and uptake becomes increasingly difficult as the soil dries. Additionally, the conductance of the soil to water declines sharply as the soil dries.

Water is held most strongly in clay soils since these soils are likely to contain the smallest capillary pore spaces. The maximum water uptake per unit root surface area occurs in the Root Hair Zone, which occurs a short distance (2-20 cm) from the root tip. As roots age, the outer surfaces become increasingly suberized and water uptake rates decrease. However, older roots can still take up a substantial amount of water since they generally make up the bulk of the root system. Water uptake is increased by the presence of Mycorrhizae fungi that form a symbiotic relationship with the roots of most higher plants. The fungal hyphae infect the root and penetrate the soil increasing the surface area for the absorption of water and mineral nutrients. In return the plant supplies the fungus with carbohydrates.

### 3.1.3 Plant Available Water

At "Field Capacity" (FC) the soil is wet and contains all the water it can hold against gravity. At the "Permanent Wilting Point" (PWP) the soil is dry and the plant can no longer extract any more water. The difference in the water content of soil between field capacity and the permanent wilting point gives the amount of soil water available for uptake by plants. The plant available water is expected to be greater for clayey and organic soils compared to sandy soils. If we know the plant available water and the rate at which this water is being depleted by crops then we can determine the necessary frequency of irrigation. Apart from irrigation scheduling, this information can also be useful in the modeling of crop growth and prediction of yields.

### 3.1.4 Water Flow Pathways in Plants

There are two major pathways for water flow in plants, the apoplastic and the symplastic pathways. In the apoplastic pathway, water moves in the free spaces (apoplast) within the plant that are unbounded by membranes and includes movement along cell walls and in intercellular spaces. In the symplastic pathway, water moves across the symplast, which consists of the cytoplasm and plasmodesmata (minute connections between the cytoplasm of adjacent cells). The resistance to water flow is higher in the symplastic pathway, largely due to the flow restriction imposed by the plasma membrane.

### 3.1.5 Water Flow across Root Cortex

Water flows from the soil across the root epidermal layer and cortex to the root xylem, with movement occurring both in the apoplastic and symplastic pathways. The apoplastic pathway is blocked at the innermost layer of cortical cells, the endodermis. The radial and transverse cell walls of the endodermis are suberized (embedded with a wax-like material) forming the Casparian strip, which prevents further movement of water along the apoplastic pathway. Both water and dissolved mineral ions from the apoplast must enter the symplast at the endodermis in order to proceed further into the plant.

### 3.1.6 Driving Forces for Water Flow from Roots to Leaves

The driving forces for water flow from roots to leaves are root pressure and the transpiration pull. Root pressure is the lesser force and is important mainly in small plants at times when transpiration is not substantial, e.g., at nights.

Root pressure requires metabolic energy, which drives the (active) uptake of mineral ions from the soil into the root xylem. As ions accumulate in the root xylem, the osmotic potential of the xylem solution falls causing the passive uptake of water from the soil by osmosis into the xylem. As pressure builds up within the xylem due to osmotic water uptake, the xylem solution is forced upward to the leaves by mass flow. Root pressure can result in the loss of liquid water from the leaves during times of low transpiration. This process is called guttation and specialized structures (hydathodes) in the leaves are involved. The maximum root pressure that develops in plants is typically less than 0.2 MPa, and this force for water movement is relatively small compared to the transpiration pull.

The transpiration pull is explained by the Cohesion-Adhesion Theory, with the water potential gradient between the leaves and the atmosphere providing the driving force for water movement. The water potential of the atmosphere is dependent on the relative humidity and temperature of the air, and can typically range between -10 and -200 MPa.

Leaf water potential typically ranges between -0.2 and -3.0 MPa. Water evaporates from the leaf surface into the atmosphere along this steep water potential gradient (no metabolic energy is required). The water potential of surface cells falls as these cells lose water and water is pulled from successively deeper cell layers along the water potential gradient created, until eventually water is pulled from the xylem vessels (Fig. 6.6). Water columns in the xylem vessels are pulled upward by mass flow as water is removed by leaf cells. Strong attractive forces between water molecules (cohesion) and between water molecules and the walls of the xylem vessels (adhesion) allow the water columns to stay intact. The typical tension (pulling force) that develops within the xylem vessels ranges between -2 and -3 MPa, which is about 10 times the force that develops under root pressure.

Cavitation can occur under water stress, which results in a snapping sound as air enters the xylem forming an embolism that blocks further water flow in that particular xylem vessel. Air embolisms may be temporary in some cases as air can redissolve in the xylem sap or be expelled by root pressure.

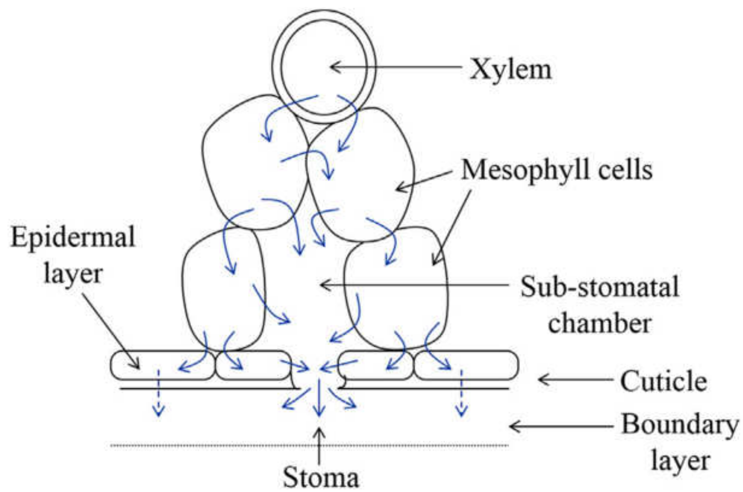


**Figure 6.6: Diagram illustrating water diffusion out of a leaf.**

### 3.1.7 Evapotranspiration

Evapotranspiration is defined as the water lost to the [atmosphere] from the ground surface, evaporation from the capillary fringe of the [groundwater table], and the transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table.

The transpiration aspect of evapotranspiration is essentially evaporation of water from plant leaves. Studies have revealed that transpiration accounts for about 10 percent of the moisture in the atmosphere, with oceans, seas, and other bodies of water (lakes, rivers, streams) providing nearly 90 percent, and a tiny amount coming from sublimation (ice changing into water vapor without first becoming liquid).

### 3.1.8 Atmospheric factors affecting transpiration

The amount of water that plants transpire varies greatly geographically and over time. There are a number of factors that determine transpiration rates:

a) **Temperature**: Transpiration rates go up as the temperature goes up, especially during the growing season, when the air is warmer due to stronger sunlight and warmer air masses. Higher temperatures cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open, whereas colder temperatures cause the openings to close.

b) **Relative humidity**: As the relative humidity of the air surrounding the plant rises the transpiration rate falls. It is easier for water to evaporate into dryer air than into more saturated air.

c) **Wind and air movement**: Increased movement of the air around a plant will result in a higher transpiration rate. Wind will move the air around, with the result that the more saturated air close to the leaf is replaced by drier air.

d) **Soil-moisture availability**: When moisture is lacking, plants can begin to senesce (premature aging, which can result in leaf loss) and transpire less water.

e) **Type of plant**: Plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

**SELF ASSESSMENT EXERCISE**

- Explain with examples Transpiration
- What are the environmental factors affecting transpiration rates
- Distinguish between root pressure and transpiration pull

## 4.0 CONCLUSION

In this unit we have discussed the meaning of various terms i.e. transpiration, The Soil-Plant Atmosphere Continuum (SPAC) and Water

Potential, Water Uptake from Soil, plant available water, Water Flow Pathways in Plants, water flow across root cortex, Driving Forces for Water Flow from Roots to Leaves. It is also learnt about evapotranspiration and the atmospheric factors affecting transpiration

## 5.0 SUMMARY

Just as you release water vapor when you breathe, plants do, too – although the term "transpire" is more appropriate than "breathe." This picture shows water vapor transpired from plant leaves after a plastic bag has been tied around the stem for about an hour. If the bag had been wrapped around the soil below it, too, then even more water vapor would have been released, as water also evaporates from the soil.

Plants put down roots into the soil to draw water and nutrients up into the stems and leaves. Some of this water is returned to the air by transpiration. Transpiration rates vary widely depending on weather conditions, such as temperature, humidity, sunlight availability and intensity, precipitation, soil type and saturation, wind, and land slope. During dry periods, transpiration can contribute to the loss of moisture in the upper soil zone, which can have an effect on vegetation and food-crop fields.

## 7.0 TUTOR-MARKED ASSIGNMENT

1. Describe transpiration in plants
2. Distinguish between root pressure and transpiration pull
3. State the atmospheric factors affecting transpiration rates

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# MODULE 7: SEED GERMINATION AND DORMANCY

**Unit 1: Seed Dormancy: Causes and Types**
**Unit 2: Seed Germination**

## UNIT 1: SEED DORMANCY: CAUSES AND TYPES

**CONTENTS**



## 1.0 INTRODUCTION

Dormancy is a condition where seeds will not germinate even when the environmental conditions such as water, temperature and air are favourable for germination.

- It is observed that seeds of some fruit plants (mango, citrus) germinate immediately after extraction from the fruit under favourable conditions of moisture, temperature and aeration.
- However, in others (apple, pear, cherry) germination does not take place even under favourable conditions. This phenomenon is called as „dormancy‟.
- This is an important survival mechanism for some species because these species do not germinate unless adverse climatic conditions end.
- In some species, chilling temperature for certain period helps in the termination of dormancy. Often dormancy is due to several factors and may persist indefinitely unless certain specific treatments are given.

## 2.0 Objectives

By the end of this unit, you should be able to:

1) Explains seed dormancy and its importance

2) Discuss the types of dormancy
3) To know about techniques for breaking different types of dormancy

## 3.0 MAIN CONTENTS

### 3.1 Types of dormancy

Different types of dormancy include

1. **Exogenous Dormancy**

- This type of dormancy is imposed by factors outside the embryo.
- In exogenous dormancy, the tissues enclosing the embryo can affect germination by inhibiting water uptake, providing mechanical resistance to embryo expansion and radicle emergence, modifying gaseous exchange (limit oxygen to embryo), preventing leaching of inhibitor from the embryo and supplying inhibitor to the embryo.

It is of three types:

a) **Physical dormancy (seed coat dormancy**): Seed coat or seed covering may become hard, fibrous or mucilaginous (adhesives gum) during dehydration and ripening as a result they become impermeable to water and gases, which prevents the physiological processes initiating germination This type of dormancy is very common in drupe fruits i.e. olive, peach, plum, apricot, cherry etc. (hardened endocarp), walnut and pecan nut (surrounding shell). In various plant families, such as, Leguminosae, the outer seed coat gets hardened and becomes suberized and impervious to water.
b) **Mechanical dormancy**: In some fruits seed covering restricts radicle growth, resulting in dormancy of seeds. Some seed covering structures, such as shells of walnut, pits of stone fruits and stones of olive are too strong to allow the dormant embryo to expand during germination. The water may be absorbed but the difficulty arises in the cementing material as in walnut. Germination in such seeds does not occur until and unless the seed coats are softened either by creating moist and warm conditions during storage or by microbial activity.

c) **Chemical dormancy**: In seeds of some fruits chemicals that accumulate in fruit and seed covering tissues during development and remain with the seed after harvest. It is quite common in fleshy fruits or fruits whose seeds remain in juice as in citrus, cucurbits, stone fruits, pear, grapes and tomatoes. Some of the substances associated with inhibition are various phenols, coumarin and abscisic acid. These substances can strongly inhibit seed germination.

**2. Endogenous dormancy**

This type of dormancy is imposed by rudimentary or undeveloped embryo at the time of ripening or maturity. This can be of different types such as morphological, physiological, double dormancy and secondary dormancy.

a) **Morphological dormancy (Rudimentary and linear embryo)**: Dormancy occurs in some seeds in which the embryo is not fully developed at the time of seed dissemination. Such seeds do not germinate, if planted immediately after harvesting. Plants with rudimentary embryos produce seeds with little more than a pro-embryo embedded in a massive endosperm at the time of fruit maturation. Enlargement of the embryo occurs after the seeds have imbibed water but, before germination begins.

Formation of rudimentary embryo is common in various plant families such as Ranunculaceae (Ranunculus), Papavaraceae (poppy). Some plants of temperate zone like holly and snowberry have also rudimentary embryos.

**b) Physiological dormancy**

Physiological dormancy is of 3 types:

i. **Intermediate physiological dormancy**: The seeds of some species require a specific period of one-to-three months of chilling, while in an imbibed and aerated state, commonly called as moist chilling. For example, most of temperate fruit seeds require moist chilling to overcome seed dormancy. This requirement led to the standardization of world famous, horticultural practice of stratification. In this process, the seeds are placed between layers of moist sand in boxes and exposed to chilling temperatures (2 to $7^0$C) for the period varying from 3-6 months to overcome dormancy.

ii. **Deep physiological dormancy:** Seeds, which usually require a relatively long (>8 weeks) period of moist chilling stratification to relieve dormancy as in peach.

iii. **Epicotyl dormancy**: Seeds having separate dormancy conditions for the radicle hypocotyl and epicotyl, is called as epicotyl dormancy e.g. *Lilium, Hepatica antiloba and trillium.*

3. **Double dormancy**

- In some species, seeds have dormancy due to hard seed coats and dormant embryos.
- For instance, some tree legumes seed coats are impervious and at the same time their embryo are also dormant.
- Such seeds require two years for breaking of dormancy in nature. In the first spring, the microorganisms act upon the seed making it weak and soft and then embryo dormancy is broken by chilling temperature in the winter next year.
- Combination of two or more types of dormancy is known as „double dormancy‟. It can be morpho-physiological i.e. combination of under developed embryo and physiological dormancy or exo-endodormancy i.e. combination of exogenous and endogenous dormancy conditions i.e. hard seed coat (physical plus intermediate physiological dormancy).

4. **Secondary dormancy**

Secondary dormancy is due to germination conditions. It is a further adaptation to prevent germination of an imbibed seed if other environmental conditions are not favorable. These conditions can include unfavorably high or low temperature, prolonged darkness and water stress. It is of two types:

a) **Thermo dormancy**: High temperature induced dormancy.
b) **Conditional dormancy**: Change in ability to germinate related to time of the year.

**Advantages**

- Permitting germination only when environmental conditions favour seedling survival as in fruit plants of temperate region.
- Helpful in creation of a “seed bank”
- Dormancy can also synchronize germination to a particular time of the year.
- Seed disposal can be facilitated by specialized dormancy conditions. For example modification of seed covering through digestive tract of a bird or other animals.

## 3.2 Seed Dormancy: Methods of breaking seed dormancy

Several methods are used for breaking seed dormancy of horticultural crops. These are briefly described hereunder:

1. **Softening seed coat and other seed coverings:** This helps in better absorption of water and gases, which ultimately leads to better germination of the seeds. This can be achieved by scarification.

**Scarification**: Scarification is the process of breaking, scratching, mechanically altering or softening the seed covering to make it permeable to water and gases. Three types of treatments are commonly used as scarification treatments. These include mechanical, chemical and hot water treatments.

**a) Mechanical scarification**

- It is simple and effective if suitable equipment is available.
- Chipping hard seed coat by rubbing with sand paper, cutting with a file or cracking with a hammer are simple methods useful for small amount of relatively large seeds.
- For large scale, mechanical scarifiers are used. Seeds can be tumbled in drums lined with sand paper or in concrete mixers containing coarse sand or gravel. The sand gravel should be of a different size than the seed to facilitate subsequent separation.
- Scarification should not proceed to the point at which the seeds are injured and inner parts of seed are exposed.

**b) Acid scarification**

- Dry seeds are placed in containers and covered with concentrated Sulphuric acid ($H_2SO_4$) or HCl in the ratio of one part of seed to two parts of acid.
- The amount of seed treated at any time should be restricted to not more than 10kg to avoid uncontrollable heating.
- The containers should be of glass, earthenware or wood, non-metal or plastic.

The mixture should be stirred cautiously at intervals during the treatment to produce uniform results. The time may vary from 10 minutes to 6 hours depending upon the species.

- With thick-coated seeds that require long periods, the process of scarification may be judged by drawing out samples at intervals and checking the thickness of the seed coat. When it becomes paper thin, the treatment should be terminated immediately.
- At the end of the treatment period, the acid is poured off and the seeds are washed to remove the acid.
- The acid treated seeds can either be planted immediately when wet or dried and stored for later planting. Large seeds of most legume

species, brinjal and tomatoes are reported to respond simple sulphuric acid treatment.

c) **Hot water scarification**

- Drop the seeds into 4-5 times their volume of hot water with temperature ranging from 77 to 100$^0$C.
- The heat source is immediately removed, and the seeds soaked in the gradually cooking water for 12 to 24 hours. Following this the unswollen seeds may be separated from the swollen seeds by suitable screens.
- The seed should be sown immediately after hot water treatment.

d) **Warm moist scarification**

- The seeds are placed in moist warm medium for many months to soften the seed coat and other seed coverings through microbial activity. This treatment is highly beneficial in seeds having double seed dormancy.
- The hard seeds are planted in summer or early fall when the soil temperature is still higher, that usually facilitates germination.
- For instance the stone fruit including cherry, plum ,apricot and peaches) show increased germination if planted early enough in the summer or fall to provide one to two months of warm temperature prior to the onset of chilling.

**Stratification**

Stratification is a method of handling dormant seed in which the imbibed seeds are subjected to a period of chilling to after ripen the embryo in alternate layers of sand or soil for a specific period. It is also known as moist chilling. However, temperate species displaying epicotyl dormancy (like fringed tree) or under developed embryo (like hollies) a warm stratification of several months followed by a moist chilling stratification is required.

Several tropical and subtropical species (like palms) require a period of warm stratification prior to germination to allow the embryo to continue development after fruit drop. The seeds can be sown after fruit drop. The seeds can be sown immediately after stratification in the field.

a) **Outdoor stratification**

- If refrigerated storage facilities are not available, outdoor stratification may be done either by storing seeds in open field conditions in deep pits or in raised beds enclosed on wooden frames.

- However it is likely that seeds are destroyed in outdoors by excessive rains, freezing, drying, or by rodents. Seeds are placed in alternate layers of sand to provide and low temperature and proper aeration in the stratification pit. The top is covered with Sphagnum moss to maintain moisture level.
- The pit or tray is irrigated at regular intervals to maintain appropriate moisture status.

**b) Refrigerated stratification**

- An alternative to outdoor field stratification is refrigerated stratification.
- It is useful for small seed lots or valuable seeds that require special handling.
- Dry seeds should be fully imbibed with water prior to refrigerated stratification.

Twelve to twenty four hours of soaking at warm temperature may be sufficient for seeds without hard seed coats.

- After soaking, seeds are usually placed in a convenient size box in alternate layers of well washed sand, peat moss or vermiculite.
- A good medium is a mixture of one part of coarse sand to one part of peat, moistened and allowed to stand for 24 hours before use. Seeds are placed in alternate layers of sand or medium.
- The usual stratification temperature is 4-7$^0$C. At higher temperature seeds sprout prematurity and low temperature delays sprouting.
- The medium should be remoistened. The stratified seed is separated from the medium prior to sowing in nursery beds.

The stratification of seeds results in quick and uniform germination and therefore the seed should be subjected to stratification invariably under all conditions.

### 3.2.1 Hormonal changes during stratification:

A triphasic change in endogenous hormones is many seeds is as follows.

- A reduction of ABA
- Increased synthesis of cytokinin and gibberellins
- Reduction in hormone synthesis in preparation for germination.
- In general, gibberellins promote germination in dormant seeds, while ABA inhibits germination.

- Pre-sowing treatments with certain seeds not only reduce the stratification requirement and improve the seed germination but also enhances seedling growth in a number of temperate fruits.

### 3.2.2 Role of hormones in seed dormancy:

Plant hormones affect seed germinations and dormancy by affecting different parts of the seed. Embryo dormancy is characterized by a high ABA/GA ratio, whereas the seed has a high ABA sensitivity and low GA sensitivity. To release the seed from this type of dormancy and initiate seed germination, an alteration in hormone biosynthesis and degradation towards a low ABA/GA ratio, along with a decrease in ABA sensitivity and an increase in GA sensitivity needs to occur.

- Plant regulators can be used to break or prolong the dormancy. Sprouting of potato tubers and onion bulbs is a common phenomenon in storage.
- Pre-harvest spray of maleic hydrazide (MH) at 2000 ppm applied 15 days before actual date of harvest prolongs dormancy in the above storage organs by inhibiting the sprouting.
- In fruit trees of apple, plums and figs, early flowering is induced by spraying Dinitro orthocresol at 0.1 % in oil emulsion.
- Seed treatment of tomato with GA at 1 00 ppm breaks the dormancy and increases the percentage of germination.
- ABA controls embryo dormancy, and GA enhances embryo germination. Seed coat dormancy involves the mechanical restriction of the seed coat, this along with a low embryo growth potential, effectively produces seed dormancy.
- GA releases this dormancy by increasing the embryo growth potential, and/or weakening the seed coat so the radical of the seedling can break through the seed coat. Different types of seed coats can be made up of living or dead cells and both types can be influenced by hormones; those composed of living cells are acted upon after seed formation while the seed coats composed of dead cells can be influenced by hormones during the formation of the seed coat.
- ABA affects testa or seed coat growth characteristics, including thickness, and effects the GA-mediated embryo growth potential. These conditions and effects occur during the formation of the seed, often in response to environmental conditions. Hormones also mediate endosperm dormancy.

- Endosperm in most seeds is composed of living tissue that can actively respond to hormones generated by the embryo. The endosperm often acts as a barrier to seed germination, playing a part in seed coat dormancy or in the germination process.
- Living cells respond to and also affect the ABA/GA ratio, and mediate cellular sensitivity; GA thus increases the embryo growth potential and can promote endosperm weakening. GA also affects both ABA-independent and ABA-inhibiting processes within the endosperm.

**SELF-ASSESSMENT EXERCISE**

1) Discuss seed dormancy and its importance
2) Enumerate the types of dormancy
3) Mention and explain the techniques for breaking different types of dormancy

## 4.0 CONCLUSION

Seed dormancy has been defined as the incapacity of a viable seed to germinate under favorable conditions since dormancy is regulated at different developmental phases, in interaction with environmental factors, it is difficult to detect when the genetic and physiological differences are established. This difficulty arises because all dormancy assays are based on seed germination, which is the result of the balance between the degree of dormancy and the capacity of the embryo to overcome dormancy. Mechanistically one can distinguish factors that influence dormancy and germination on the basis of their effect on germination, being either inhibiting or promoting. Mutants that germinate better or faster can represent genes that promote dormancy or those that repress germination. A further distinction can be made by defining the timing and site of action of these factors (during maturation or during imbibition of the seeds, in the embryo, the endosperm or in the testa). The interaction between these factors and the large effect of the environment, both during seed development and during imbibition, make seed dormancy a very complex trait.

## 5.0 SUMMARY

Seed dormancy allows seeds to overcome periods that are unfavourable for seedling established and is therefore important for plant ecology and agriculture. Several processes are known to be involved in the induction of dormancy and in the switch from the dormant to the germinating state. The role of plant hormones, the different tissues and genes involved, including newly identified genes in dormancy and germination are described in this unit, as well as the techniques in breaking seed dormancy for successful germination.

## 6.0 TUTOR-MARKED ASSIGNMENT

1) Discuss
   a) Seed dormancy and
   b) Its importance in seed germination
2) Enumerate the types of dormancy
3) Mention and explain the techniques for breaking different types of dormancy

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## UNIT 2: SEED GERMINATION

**CONTENTS**



### 1.0 INTRODUCTION

Germination is the crucial and final event in the life of a seed. It represents both the fulfillment and the completion of the basic function of seed - propagation. Seed - to be sure - have other functions in modern agriculture. They are the main mechanism by which improvements genetically engineered into plant populations are transmitted from one crop generation to another. They also function very efficiently as a convenient means of distributing plant populations throughout areas of adaptation. The latter two functions, however, are wholly dependent on germination. A seed that has lost its capacity for germination can neither transmit genetic improvements nor function in the distribution of desirable plant populations from one place to another.

Seed are produced to propagate crops and other desirable plant species. A substantial portion of the operations and activities involved in seed production and supply are designed to maintain, protect, and/or enhance the propagative value of seed, i.e., capacity to germinate. Seedsmen, therefore, should have a good understanding of the germination process and its vulnerabilities. Germination is the resumption of active growth of the embryonic axis in seed.

### 2.0 OBJECTIVES

By the end of this unit, you should be able to:

1) Explains seed germination and the various types
2) Discuss the factors affecting germination
3) Explain the concept "Mobilization of energy and food reserves in germination''

### 3.0 MAIN CONTENTS

### 3.1 Process of Seed Germination

The activation of metabolic machinery of seed embryo is the first and foremost step to initiate the seed germination process Thus, seed germination is the process of reactivation of the metabolic activity of the seed embryo, resulting in the emergence of radical (root) and plumule (shoot), thus leading to the production of a seedling or a young plant.

Seed germination is a very complex process as it involves many biochemical, physiological and morphological changes within a seed. For germination to be initiated, three conditions must be fulfilled First, the seed must be viable i.e the embryo should be alive and capable of germination. Second, the seed should be non-dormant i.e there should not be any dormancy or any chemical barrier for germination Third, the environmental conditions like moisture, temperature, air ($O_2$) and light must be available in appropriate amount. If all these conditions are fulfilled, the quiescent embryo in the seed will resume growth, thus initiating the process of germination. In the early stages of growth, the embryo draws nutrients from the stored food material in the cotyledons or the endosperm of Later, new shoot/leaves are developed, which produce their own photosynthetic system.

### 3.1.2 Stages of seed germination

The process of seed germination involves several consecutive but overlapping events like

i. Absorption of water,
ii. Initiation of cell enlargement and division,
iii. Increased enzymatic activity,
iv. Food translocation to growing embryo,
v. Increase in respiration and assimilation,
vi. Increase in cell division and enlargement and
vii. Differentiation of cells into tissue and organs of a seedling.

The sequence of these events is not specific and one event may overlap the other. However, the entire process of germination can be divided into following different stages:

1. **Activation or awakening stage:**

a) **Water absorption:** Early seed germination begins with the imbibition of water by the seed. Water is absorbed by the process of imbibition and osmosis by the dry seeds, which softens the seed coat and other coverings and causes hydration of the protoplasm. After imbibition of water, the seed swells and seed coverings rupture, which helps protoplasm in resuming metabolic activity with the activation of enzymes. During hydration phase, the seed coat acts as a limiting factor and its rupture increase water uptake. Water enters the seed through micropyler pore and hilum. In general, water absorption is very rapid initially but it slows down slowly and steadily.

b) **Synthesis and activation of enzymes:** After hydration, enzyme activity begins very quickly. Activation of enzymes is partly from reactivation of stored enzymes and partly by the synthesis of the enzymes during germination initiation process. The hydrolytic enzymes convert complex food material into simpler forms, which can be readily translocated and absorbed by the embryo. The oxidative enzymes are involved in respiration and releasing the energy for cell division and growth.

c) **Cell elongation:** Hydration, and synthesis and activation of enzymes help in the elongation of cells, which results in the emergence of radicle. Emergence of radicle is the first visible symptom of germination, which results from the elongation of cells rather than from the cell division. It is observed that under fabvourable conditions, the emergence of radicle may take place within a few hours as in non-dormant seeds or a few days after seed sowing. The emergence of radicle is considered as the end of stage 1 i.e. activation or awakening stage.

**2. Translocation stage:**

Food materials like fats, carbohydrates or proteins are stored in the endosperm or in the cotyledons. These compounds are converted into simpler forms and are translocated to the growing points of the embryo. The process of conversion of different speces differs with the type of food material reserved in the seed. For example, fat and oils are converted enzymatically to first to fatty acids and then to sugars. Storage proteins are first converted to amino acids and then to nitrogen, which are essential to growing seedlings. Starch present in many seeds as an energy source, is converted to simple sugars. All these conversions are regulated by metabolic activity of specific enzymes in a proper sequence.

**3. Seedling growth stage:**

In this stage, the development of the seedling plant takes place from continued cell division in different growing points of the embryo, which is subsequently followed by the expansion of the seedling structures. The cell division is growing point and subsequent cell elongations are two independent processes taking place in a seedling. As the germination proceeds, the structure of seedling soon becomes evident.

### 3.1.3 Types of seed germination:

The radicle, the growing point of root emerges from the base of the embryo axis and the plumule, the growing point of shoot is at the upper end of embryo axis, above the cotyledons.
The section of seedling stem above the cotyledons is called as epicotyl and below the cotyledons is called as hypocotyls.

**Two types of germination are commonly found in cultivated plants.**

1. **Epigeal germination:** Seed germination in dicots in which the cotyledons come above the soil surface. In this type, the hypocotyl elongates and raises the cotyledons above the ground surface, it is called as epigeous or epigeal germination. This type of germination is very common in beans, gourds, castor, tamarind and onion etc.

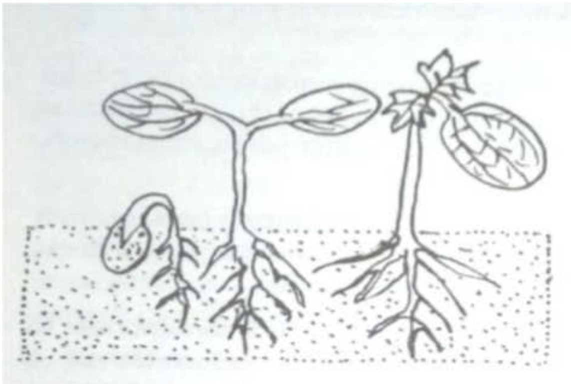

**Fig 7.1: Epigeal Germination**

2. **Hypogeal germination:** Seed germination in dicots in which the cotyledons remain below the soil surface. In this type, the epicotyl elongates and the hypocotyl does not raise the cotyledons above ground, which is called as hypogeous or hypogeal germination. This type of germination is common in mango, custard apple, pea, gram, lotus and maize etc.

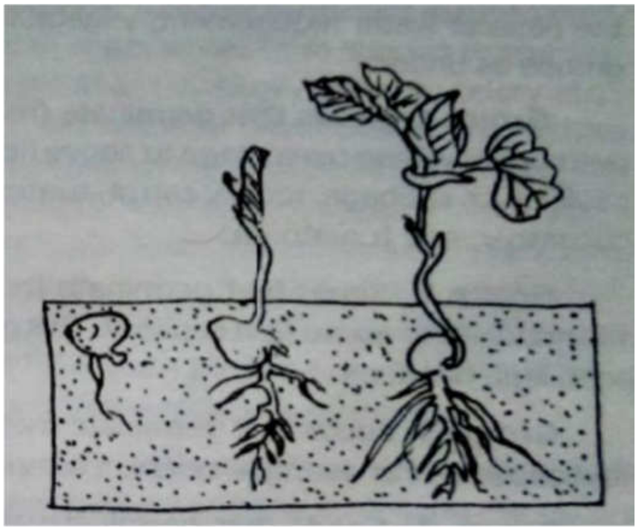

**Fig 7.2: Hypogeal Germination**

### 3.1.4 Mobilization of Energy and Food Reserves

The absorption of water by seed "turns on" and/or accelerates metabolic processes which lead to the resumption of active growth of the embryonic axis in the seed and support early seedling development. One of the basic processes accelerated is respiration.

Energy is required for the resumption of active growth of the embryonic axis – for germination and many of the processes that support germination. The energy required is provided by respiration. An air dry seed at 10-13% moisture content respires but at a very low rate. During the water absorption phase of the germination process, the rate of respiration increases dramatically. Some of the energy released during respiration is in the form of heat, but most is converted from some chemical forms to others.

The process of respiration requires a readily available substrata - an organic compound which can be oxidized to release energy. The basic respiratory substrate is a simple sugar called glucose. During respiration glucose is oxidized by complicated processes to carbon dioxide and water with the release of a substantial quantity of energy. In green plants the organic compounds required for respiration are formed by the process of photosynthesis, thus the sun is the ultimate source of energy for plant growth and the production of seed and the other plant materials that man harvests.

Since photosynthesis is not re-established until after germination is complete and the seedling has developed to a certain extent, the germination process is dependent on reserve organic compounds stored in the seed for energy and other materials. Some of those organic compounds are in the embryonic axis in readily usable forms, e.g., sucrose, and serve as respiratory substrata for the early phase of the germination process. The bulk of the reserve materials, however, are in the form of complex, non-mobile (non-translocatable) forms located in specialized tissue within the seed. These compounds must be broken down to simple, translocatable forms to make them available for germination. The reserve materials in seed occur in three major forms: starch and other complex carbohydrates, fats and oils, and proteins. The processes which transform these materials into usable, translocatable forms are termed "mobilization of reserves."

Starch is the principal reserve in cereals and other species of the grass family. It is stored in the endosperm. During the early phase of germination, gibberellin, a hormone present in the scutellum (part of the embryo or gem), moves into the outermost layer of the endosperm and stimulates the activity of hydrolytic enzymes which catalyze the breakdown of starch into glucose. One of the steps involved in the breakdown of starch is the production of maltose, which is, of course, important in the brewing industry. Glucose is a simple sugar and easily translocated. It moves from the endosperm into the scutellum where it is converted into sucrose. Sucrose is then translocated to the active sites in the embryonic axis for use. The mobilization of stored starch and other complex carbohydrates in non-grass species such as peas is somewhat different but the end result is the same - respiratory substrata is made available to the active sites of the embryonic axis.

When all plant species are considered, the most frequent reserve material is fats and oils. The evolutionary significance of this situation is that fats and oils – or lipids - have a higher energy value than starch or proteins. Fats and oils are broken down by enzymic activity to fatty acids and glycerol. Glycerol is further broken down to simple compounds which can enter into the respiratory process, or it can be incorporated in "new" fats and oils. Likewise, the fatty acids are further degraded into fragments that are readily usable in the respiratory process or for re-conversion into other materials.

The proteins stored in seed are broken down by enzymic activity into amino acids. The amino acids liberated are translocatable and are used for synthesis of the new proteins required for other enzymes, and new plant material, i.e., for growth. Or, they can be oxidized to provide energy.

The reserve materials stored in seed provide the energy and "building blocks" needed for resumption of active growth of the embryonic axis and growth and development of the young seedlings. These materials are made available to the embryonic axis by "mobilization" processes. As the seedling develops, photosynthesis is re-established and it becomes independent of the reserves stored in the endosperm or cotyledons which decay or shrivel and drop from the seedling. Man cultivates many species of plants for the reserve materials stored in seed for his own consumption or for animal feed. Wheat and other cereals are milled to produce flour for bread and pastries or for brewing. Rice is consumed directly.

**SELF-ASSESSMENT EXERCISE**

1) Discuss the process of seed germination
2) What are the stages in seed germination
3) Mention and explain the types of germination

## 4.0 CONCLUSION

In this unit, seed germination is discussed, the various types of germination and the factors affecting seed germination was also discussed. The process of seed germination, process of seed germination as well as the mobilization of energy and food reserves as it relates to seed germination was discussed in this unit. It is concluded that germination incorporates those events that commence with the uptake of water by the quiescent dry seed and terminates with the elongation of the embryonic axis. Water uptake by a seed is triphasic; phase I rapid initial uptake; phase II plateau phase and in phase III further increase of water uptake, however, only when germination occurs. The first signs of germination are the resumption of essential processes, including transcription, translation and DNA repair followed by cell-elongation and eventually at the time of radicle protrusion, resumption of cell division. . Physically germination is a two-stage process, where testa rupture is followed by endosperm rupture. Following rupture of the micropylar endosperm by the emerging radicle, germination is complete

## 5.0 SUMMARY

Germination is the crucial and final event in the life of a seed. It can be defined as the resumption of active growth of the embryonic axis. A seed requires moisture, a favorable temperature and oxygen for germination.

Rehydration of the seed sets in motion a chain of reactions which provide the energy and building blocks for the resumption of active growth and development of the young seedling. Germination failure is caused by many factors and conditions. These range from deterioration of the seed and loss of the germinative capacity to the mechanical impedance to emergence from soil crusts formed after sowing.

## 6.0 TUTOR-MARKED ASSIGNMENT

1) Discuss the process of seed germination
2) Explain mobilization of energy and food reserves in respect to germination
3)
4) Discuss the various types of germination

## 7.0 REFERENCES/FURTHER READING

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# MODULE 8: PLANT MORPHOGENESIS AND MORPHOGENETIC FACTORS



## UNIT 1 BASIC IDEA OF MORPHOGENESIS AND CONCEPT OF DIFFERENTIATION

**CONTENTS**



## 1.0 INTRODUCTION

Morphogenesis is defined as a process concerned with formation and development of whole plant, a part of plant or a specific structure. During very early developmental stages polarity is established at the zygote stage due to which a polar difference is developed at both the ends of zygote. Cytological differences at the two ends determine the position of first cell division and also the fate of the structure which will be produced by the two cells (cells formed by division of zygote). Different parts of plant have different type of morphology. This diversity in different parts of plant is produced due to variation in growth rate of different parts and also because different parts show growth in different dimension. Rate of cell division, cell elongation along with orientation of plane of division and axis of cell elongation altogether establish the form of structure of plant.
Polarity is not limited to initial developmental stages but polarity is maintained throughout the growth. Plant axis (shoot and root tips) also exhibits polarity, If a portion of shoot is excised (cut) and allowed to regenerate the end toward shoot tips will always form shoot whereas end towards root will regenerate roots. As in stem polarity is also exhibited in other organs like upper and lower surface of leaf, petals, sepals etc.

During their growth and development plant, cells exhibits a specific phenomenon called as totipotency. It is the ability of a cell to give rise to different types of cells and eventually lead to regeneration of a complete plant. Meristematic cells get differentiated to attain specific functions once the cell gets differentiated. They lose their ability to divide. However, differentiated plant cells can undergo a process of redifferentiation (specially during plant tissue culture) and can

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Understand basic idea of morphogenesis and concept of differentiation
- To know about how is polarity developed and how it affects morphogenesis
- To understand role of totipotency in growth of plants and in plant tissue culture

## 3.0 MAIN CONTENTS

### 3.1 Morphogenesis and Concept of Differentiation

The word morphogenesis comes from Greek words *morphe* (which means shape) and *genesis* (which means creation) to indicate a process of formation of a particular structure with a specific shape and size.

Morphogenesis is considered to be a biological process which causes an organism to develop its shape. Morphogenesis is concerned with development of particular part or structure. Plants possess a longer period of morphogenesis. During development plants (unlike animals) do not exhibit a distinct body plan. Plants may grow and develop on and on till they die. This is because plants have meristematic tissue composed of actively dividing cells which result in formation of more and more new tissues, organs and structures throughout the life of plant.

The term differentiation was first of all used by Karl Willhelm. Differentiation refers to a process in which distinct (different) types of cells are formed from a precursor cell. Differentiation is a permanent localized qualitative change in size, biochemistry, structure and function of cells, tissues or organs. A cell which has ability to get differentiated into different cell types of an adult organism is called pluripotent. In plants such cells are also called as meristematic cells.

Different type of structural changes occurs inside a cell during the process of differentiation. These changes may occur in cell wall, protoplasm or both. For example when a cell gets differentiated into tracheary elements it loses its cytoplasm and the cells develop an elastic, strong, lingo cellulosic secondary cell wall to carry out transport of water.

Hence, meristematic cells are group of unspecialized (undifferentiated) cells which are capable of dividing throughout the life of plant and can get differentiated into different types of cells. When a cell gets differentiated it acquires specific morphological, physiological as well as biochemical properties. During growth and development of plant meristematic tissue give rise differentiated tissue where each cell has specified structure and function. Differentiation cells do not have ability to divide. In an another process known as dedifferentiation, differentiated tissue loses its differentiated state and becomes undifferentiated.

Such undifferentiated tissue can again undergo the process of differentiation known as redifferentiation and again become differentiated with specific structure and function. A dedifferentiated cell can divide and produce new cells (Fig.8.1). Dedifferentiation is a commonly observed phenomenon during secondary growth in plants and also during the process of healing of wounds.

**Secondary** growth happens when stems or branches grow outward (get thicker) This type of growth is possible because some plants (like trees and shrubs) have lateral meristem, another stem cell like tissue. Instead of causing the plant to grow up or down, lateral meristematic tissue causes the plant to increase in girth by adding rings of growth. Now we know how a plant gets taller and its roots get longer. But what about being wider? Even a big tree with an enormous trunk starts out as a puny seedling. So when the width of a plant or its girth increases is called secondary growth and it arises from the lateral meristems in stems and roots.

Secondary growth is growth at the lateral meristem and increases the girth of the stem. This type of growth is only found in dicots and is not found in monocots. In order to understand why it does not occur in monocots, let us review the structure of vascular tissue in both types of flowering plants. There are two types of vascular tissue: xylem, which moves water and dissolved minerals, and phloem, which moves food in the plant stem. In monocots and dicots, these structures are organized a bit differently.

In monocots, the xylem and phloem are found in paired bundles and are scattered throughout the stem. Remember that monocots are simple flowering plants such as grasses. However, in dicots - which are more advanced flowering plants such as roses and apple trees - the xylem and phloem are found in rings with the xylem on the inside and the phloem on the outside. This organization allows for secondary growth of plant stems. Plant cells are totipotent and possess an inherent ability to undergo process of differentiation to give rise to different types of cells, which ultimately form different organs in plant system.

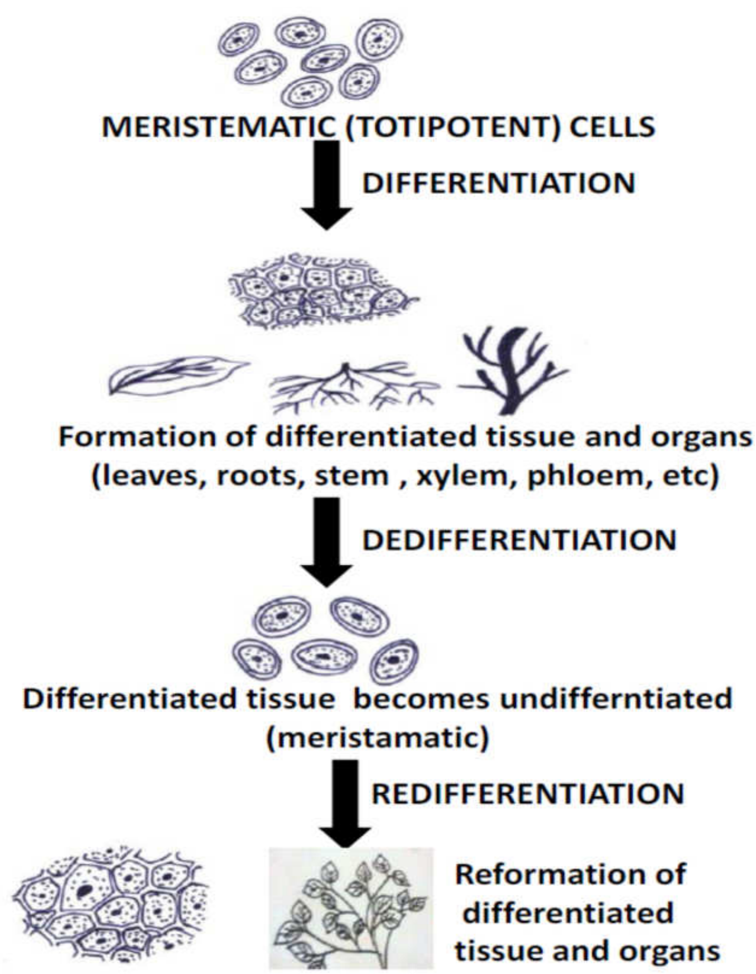


**Fig. 8.1: Diagrammatic representation of differentiation, dedifferentiation and redifferentiation**

## 3.2 Polarity

The term polarity means specific orientation of plant activity and morphogenesis in space. Plants are multicellular organisms made up of cells, tissue and organs. As we already know that in a multicellular organism cells, tissue and organs are integrated with one another to bring about overall functioning of an organism. There are many factors which regulate and control this integrated functioning. Among different factors polarity is one the most important factor of plant integrity. In plants axial polarity, dorsiventral polarity and radial polarity are known. However, when we talk of polarity in plants we generally refers to axial polarity. Axial polarity means presence of a well defined longitudinal axis which bears lateral organs such as lateral branches, roots, leaves and flowers. The radial axis is most clearly evident in dicotyledonous species as the concentric rings of cell layers stem, hypocotyl and root with an increase in size across this axis can arise from the generation of new cell layers following divisions in the vascular cambium in the older plant.

There are several factors which influence polarity in plants. Physical factors like light, gravity, electric and magnetic field, chemical agents such as plant growth regulators and ions influence polarization in plants. Polarization is related to axial gradient of bioelectric potential (BEP) which develop from gradient of $Ca^{2+}$, $K^{+}$, $H^{+}$ etc. A change in membrane permeability to these ions generates a dielectric potential. Results obtained from studies conducted on plants such as *Arabidopsis, Capsella bursa-pastoris* have made it clear that apical-basal polarity is determined even before the first zygotic division in the egg.

Early events of zygote polarization have been very well studied in *Fucus* (brown alga). In *Fucus* polarization of zygote is initiated and influenced by various types of stimuli such as unidirectional light, temperature, electric field or chemical gradient. Axis formulation is associated with redistribution of plasma membrane components. $Ca^{++}$ is the most important component which gets accumulated toward basal end during axial axis function.

In *Arabidopsis* during axial polarization, zygote divides by an asymmetric transverse division resulting in formation of two daughter cells of unequal size. One is the basal cell which is derived from vacuolar region and is larger in size and another cell is smaller upper cell which is derived from

cytoplasmic region. Upper cell divides to form suspensor (containing six to nine cells). Only the upper most cell of suspensor called hypophysis is actually the part of embryo proper.
There are two systems under which induction of polarity in plants have been studied.

1) The first system of polarity in plants is ROOT- RHIZOID POLARITY, this type of system studied in phaeophycean zygotes and in pteridophytic spores. Development of polarity occurs parallel to ionic gradient of calcium, potassium and sodium. During polarization an increase influx of calcium ions occurs into the cell present in the future rhizoid pole. On the contrary a decreases influx of calcium ions occur in the opposite pole.
2) Another system of polarity is SHOOT-ROOT POLARITY found in higher plants: (Development / induction of polarity in multicellular plants)

The earliest work related to shoot-root polarity was done by Marquis Duhamel du monceau in eighteenth century. In his work existence of two morphogenetic factors was proposed, one was a heavy root sap and a light shoot sap. Both morphogenetic factors (shoot sap and root sap) were directed by gravity to their respective poles, where they got accumulated and shoot sap initiated formation of shoots and root sap gave rise to roots. Zygote displays a specific cell polarity with a vacuolar pole present at micropylar site (which later develops into suspensor or root pole) and an opposed cytoplasmic pole (embryo pole). Establishing polarity is an important event for morphogenesis and development of plant. Particularly in plants polar differences can be identified at very early stage of development after the formulation of zygote. During the process of development of plant, polarity can also be seen in plant axis i.e. in shoot and root tips. This means that once a polarity is established it does not gets altered naturally. So if a part of shoot or root is existed and allowed to regenerate the end toward shoot tips always regenerates into shoot and the opposite end will develop roots. However, during the process of development either removal of one part of plant or changes in a part of plant significantly affect morphogenesis of one or more other parts of plant. This process is called as correlation and is generally mediated through nutrient and plant growth regulators.

## 3.3 Totipotency

### 3.3.1 Basic concept of totipotency

Totipotency refers to inherent genetic potential of a plant cell to regenerate into complete plant. Plant cells can follow a developmental pathway similar to that of a zygote resulting in formation of new plant. The concept of regeneration the entire plant from a single cell or tissue was conceptualized by G. Haberlandt in 1902, who is known as father of plant tissue culture.

F. C. Steward along with his colleagues developed a method for growing carrot tissue by taking small part, from the secondary phloem region of carrot root. This part was utilized as explants in the experiment. The explants were cultured by placing it onto a liquid medium under aseptic conditions. During the culture process the phloem tissue began to grow. Initially some single cells and some groups of cells became loosened from the surface of growing tissue and started growing separately. Some single cells developed somatic embryos or embryoids by a process now known as somatic embryogenesis. The embryo ultimately gave rise to shoot and root and the complete plant was regenerated (Fig.8.2).

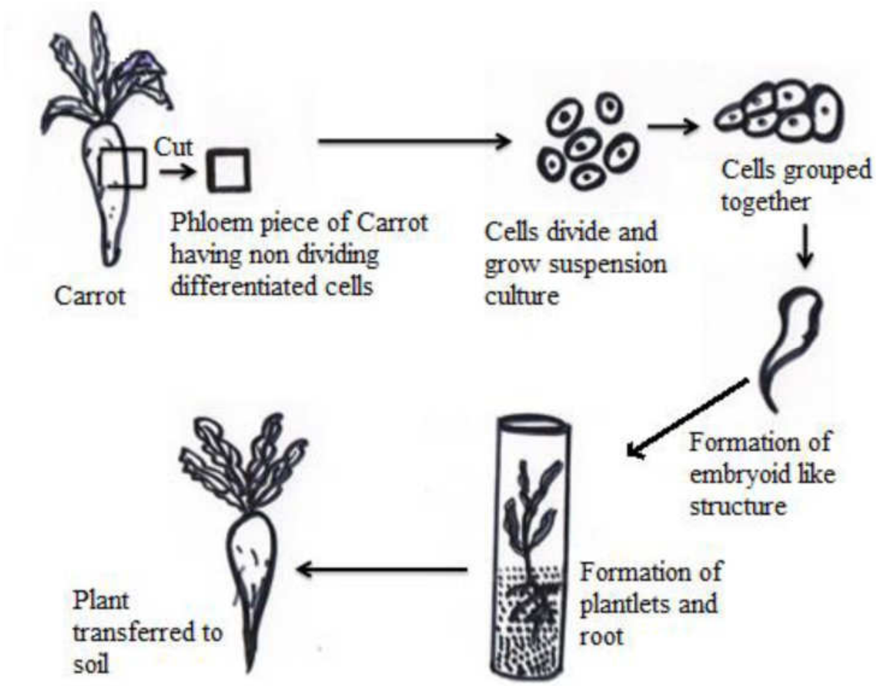


**Fig. 8.2: Regeneration of complete plant (carrot) from single cell**

### 3.3.2 Importance or significance of Totipotency

- The most important aspect/application of totipotency is reconstruction or regeneration of complete plant from any tissue or organ.
- Regeneration of plants from somatic cells through their ability totipotency has been utilized for vegetative propagation of many medicinal, aromatic and ornamental plants with economic importance.
- With the development of plant tissue culture technology large number of plants can be produced in short time interval. Totipotency is the underlying principle of regeneration of plants through plant tissue culture. Hence, endangered, rare and scarce plants can be mass propagated through the technique.
- Advancements made in plant science have resulted in development of genetically modified plants. Production of homozygous plants, haploid plants, somatic embryogenesis, somatic hybridization, protoplast (fusion and) culture etc. Totipotency is the basic of all the above mentioned developments made in plant science.
- *In vitro* regenerated cells, tissue, callus with totipotency potential can be preserved for long periods under liquid nitrogen. The process is known as cryopreservation. Whenever required these cells can be retrieved thawed and can be utilized for regeneration (since they are totipotent)

### 3.3.3 Totipotency and plant tissue culture

Plant tissue culture also known as *in vitro* micropropagation is a technique utilized for regeneration of plants under controlled conditions. The technique has been successfully utilized for regeneration, conversation of large number of medicinal, aromatic, ornamental and other plants on a large scale.

The entire success of plant tissue culture technology is based upon the totipotency of plant cells.

Normally, we grow plants mainly through seeds or by methods of vegetative propagation including cutting, grafting, layering etc. But through the technique of tissue culture plants can be regenerated by culturing any part of the plant. The part of plant (cell, tissue, organ) excised to culture is called as explant. Explants are transferred to a culture medium aseptically. The cultures are then incubated under suitable temperature with proper light.

Now, during the process of incubation the explants which are differentiated tissue undergo the process of dedifferentiation and become undifferentiated and totipotent. Explants now undergo the process of redifferentiation and start growing to regenerate a new plant. In tissue culture process growth can be of two types direct and indirect. In direct growth formation of organs (shoots, roots or embryo) occurs directly from explant whereas in indirect growth first a callus (undifferentiated mass of cell) is formed. By further sub culturing this callus regeneration of shoot and roots can be obtained. The plant regenerated in laboratory conditions are then transferred to soil (natural conditions) through a process known as hardening or acclimatization.

Hence, totipotency forms the basis of plant tissue culture through which large number of plants can be regenerated in comparatively shorter duration of time.

There are several advantages of plant tissue culture.

a) Production of large number of plants.
b) Conservation of endangered species.
c) Production of hybrid plants.
d) Synthesis of secondary metabolites.
e) Production of virus resistant plants through meristem culture.

**SELF ASSESSMENT EXERCISE**

- Explain the basic concept of morphogenesis and concept of differentiation
- How is polarity developed and how it affects morphogenesis
- Discuss the role of totipotency in growth of plants and in plant tissue culture

## 4.0 CONCLUSION

In this unit, it is learnt that dedifferentiated cells can again differentiate by a process known as redifferentiation. Meristematic cells divide and differentiate to form different types of cells with specific structure and function. A differentiated cell looses their ability to divide. Structural changes occur inside a cell during the process of differentiation. These changes may occur in cell wall, protoplasm or both. Differentiated plant cells can undergo a process of dedifferentiation and can again become meristematic .There are two systems under which induction of polarity in plants have been studied, they are root- rhizoid polarity and shoot-root polarity. Root- rhizoid type of polarity is studied in Phaeophyceae and Pteridophytes. Shoot-root polarity type of polarity is studied in higher plants. Gradient of calcium, potassium and sodium across the cell membrane play an important role in development of polarity. Once a polarity is established, it does not get altered naturally. Changes in a part of plant significantly affect morphogenesis of one or more other parts of plant.

Totipotency is the ability of a cell to give rise to different types of cells and eventually lead to regeneration of a complete plant. Totipotency is reconstruction or regeneration of complete plant from any tissue or organ. Totipotency forms the basis of plant tissue culture through which large number of plants can be regenerated in comparatively shorter duration of time.

## 5.0 SUMMARY

Morphogenesis is defined as a process concerned with formation and development of whole plant, a part of plant or a specific structure. During very early developmental stages polarity is established at the zygote stage. Due to this polarity difference at both the ends of zygote is established according to which different structures are developed at different poles. Axial polarity is most significant polarity pattern in plants which is represented by longitudinal axis which bears lateral organs such as lateral branches, roots, leaves and flowers. Different parts of plant have different type of morphology. This difference develops due to difference in growth pattern, growth rate and different dimension of growth.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between differentiation, dedifferentiation and redifferentiation?
2. Define totipotency? Mention the significance & importance of totipotency?
3. Enlist few applications of plant tissue culture?
4. Define polarity? Citing suitable examples mention about shoot root and root- rhizoid?

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**UNIT 2: MORPHOGENETIC FACTORS**

**CONTENTS**



## 1.0 INTRODUCTION

Different factors (called as morphogenetic factors) affect growth and development of plants. These factors can be environmental such as light, temperature, water or nutritional factor, physical factors such as gravity, pressure and genetic factor. Genes are considered to be the ultimate factor which growth but they do not regulate growth independently. Instead genes interact with existing environmental conditions to control plant development.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- Understand the different morphogenetic factors and how they affect morphogenesis of plants

## 3.0 MAIN CONTENTS

### 3.1 Basic concept and effect of morphogenetic factors

Morphogenetic factors are physiological factors which induce regulate and coordinate morphogenetic events in plants. These factors can be a part of inner or outer environment of the plants.

Morphogenetic factor can be divided into two groups:

a) Environment factors
b) Genetic factors

Plants are multicellular organisms which survive in an environment which is complex and keeps on changing. Genetic makeup (genome/total genes present in nucleus) remains unchanged except for rarely occurring somaclonal variation. Now, even since there is no change in genetic constitution of plant but plants do exhibit phenotypic changes i.e. their appearance changes or gets modified with changes in their environment. Such phenotypic changes which occur in plants are considered to have occurred due to environmental factors. However it is quite difficult to judge whether the morphogenetic change occurring in plant is due to a genetic factor or an environmental factor since both environmental as well as genetic factors are operating simultaneously. Responses such as flowering, thickness of cuticle, height of plant are greatly influenced by environment and get altered according to the changing environment (change in temperature, pH, light, moisture etc). Whereas characters such as formation of pits on side walls of vessels, arrangement of leaves etc do not change with the change in environmental conditions. The degree of lobbing in leaves is greatly influenced by changes in temperature.

Another class of factors which influence plant growth or morphogenesis are nutrients. They act as chemical factors, come into plant body from outside and participate in biochemical process occurring inside the plant. There are several growth substances which significantly influence morphogenesis in plants.

**There are three possible attributes of action of morphogenesis factors.**

1) It is not necessary that a morphogenetic factor may directly result in a response but it may act as a stimuli to trigger other biochemical reaction in an organism.
2) One morphogenetic factor can significantly influence or modify the action of another factor. No factor can act independently; response mediated by each factor is dependent upon the environment as well as on the status of plant.
3) A plant is not a constant system i.e. character of plant changes from one phase of life cycle to another and also from one part of plant to other part of the plant. Hence, plants may exhibit different response to same morphogenetic factor in different phases of life cycle. And also different part of plant may respond differently to same morphogenetic factor.

### 3.1.1 Morphogenetic effect of light

As we all know that light is one of the most crucial factors for growth, development and survival of plants. Light is required by the plants for vital processes such as photosynthesis, photo morphogenesis etc. Beside these processes, light also influences several other physiological processes. One of the most prominent effect of light as morphogenesis factor is that any plant reaches its maximum height with optimum growth only when the plant is exposed to sufficient amount of light. If insufficient light is provided the plants exhibited retarded growth even if supplied with sufficient water, nutrients and temperature.

There are three aspects of light which influence growth of plants:

a) **Intensity**: It is the measure of brightness of light or other illumination i.e. actual energy of the radiation.
b) **Quality:** It refers to wavelength of the light perceived by plants.
c) **Duration:** By duration it means the length of lightness (day) and darkness (night) to which a plant is exposed.

The effect of light can have different effect on different parts of plant. Some of the effects of light on plants are:

- Rate of photosynthesis generally increases with increase in intensity of light to a certain extent.
- Intensity of light also affects qualitative traits such as strength of stem, development of xylem and phloem etc.
- Plants grown in shade have comparatively small root system.
- Light intensity is directly proportional to width of stem.
- Some herbaceous plants show zig-zag growth pattern in light but grow straight if same plants are grown in darkness.
- Whenever we think of light and plants, we get an image that light is required for photosynthesis by plants. But light is also needed by plants which lack chlorophyll.
- Etiolation is an important effect of light intensity. Plants grown in darkness are somewhat with pale leaves, weak roots and poorly developed xylem and phloem.
- Longer wavelength of light (red light) enhances elongation cells and tissues whereas blue light tends to present elongation.
- Quality of light also effects flowering in plants.
- Beside quality duration of light (photoperiodism) also effects flowering in plants.
- The length of photoperiod may also effect differentiation of sex e.g. in Cannabis sativa, when 16 hour photoperiod is given flowering occurs within 4-6 week. About half plants are male and half females. However, same plants when provided with 8 hours photoperiod, enhanced and fast development occurs with flowering occurring within 3-4 weeks and about half the plants are hermaphrodites and half females.

### 3.1.2 Morphogenetic effect of water

Water is another important morphogenetic factor which influences growth, development and morphogenesis in plants. Water is one of the key requires for photosynthesis to occur. Deficiency of water results in phenomenon known as xeromorphy. On the contrary presence of excess amount of water result in small roots. Poor development of mechanical and vascular tissue, leaves become then stomata are reduced or absent. These traits are generally regarded as adaptation to survive in aquatic environment. It has been found through several studies conducted by different scientist that there exists a definite correlation between the amount of water passing through the vascular tissue and the amount of vascular tissue developed.

Water also exerts other morphogenetic effects. Development of positive hydrostatic pressure generally occurs at early and rapid leaf growth and leads to formation of larger leaves. When the hydrostatic pressure is low at later stage smaller leaves are developed.

### 3.1.3 Morphogenetic effect of temperature

For all living organisms including plants temperature is a crucial factor which influences morphogenesis as well as metabolic processes occurring inside the organism. A peculiar feature about temperature is that most of the responses mediated by temperature are equally affected by light. The most important effect of temperature is on the growth of plant. Like any other living organisms plants also need an optimum temperature for growth and development. However, the optimum temperature may vary from one plant species to another, same plant may require different temperature during different phase of life cycle and moreover optimum temperature may be different for different region of plant.

As we study the concept of photoperiodism similarly there exists thermoperiodism. It refers to daily rhythm in reaction to temperature. If plant is provided with constant temperature throughout 24 hours, many plant show slow growth as compared to the growth obtained when the same plants are grown in comparatively warmer days and cooler nights.
A plant usually contains many buds out of which several buds do not develop. Significant amount of study has been conducted to find out which factors or growth substances decide that which bud will develop and which will not. Temperature is one the crucial factors which influences breaking of bud dormancy. Low temperature is considered to be an effective treatment for breaking dormancy.

Another morphogenetic effect of temperature is observed in form of vernalization. Vernalization is a process of providing low temperature for induction or acceleration of flowering. For some plants vernalization is a must for flower to occur. In Horticulture practice, seeds and seedlings are intentionally given treatment of low temperature to induce early flowering. In a study conducted by Burstrom (1956) it was found that exposure to high temperature results in reduction in length of root cells. This is due to shorter period of cell elongation.

### 3.1.4 Morphogenetic effect of mechanical factors

Physical factors such as compression, tension, bending and swaying, gravity also effect growth and development of plants. These factors are also referred to as mechanical factors. These factors may be called as mechanical but they are quite simple in character as compared to temperature and light. Mechanical factors influence morphogenesis indirectly by affecting the physiological process occurring in plants.

There are plants which display thigmotropism (response to contact). This type of response also involves morphogenetic changes. For example, when a tip of a tendril is touched by another branch or wire any other material tendril tends to coil around the wire or branch to provide support to the plant. This response involves enhanced growth of tendril in the direction of the support. When the stem of herbaceous plant bents, smaller cells are formed on convex side where as thick walled cells are formed on concave side. This difference is due to mechanical strain. Cells on convex side are under tension and cells on the concave side are under compression.

Gravity is another factor which influences growth of plants. Unlike other morphogenetic factors gravity is continuous, unchanging in intensity and also constant in direction. Downward growth of primary root, upward growth of main stem, etc are considered to be manifestations of geotropic growth reaction. Effect of gravity and light appears to be indistinguishable from one another. A change in relation to one generally produces a change in relation to the other. However unlike light (which directly affects morphogenesis) gravity exerts an indirect effect (by
Influencing other factors) on plant. Gravity is also known to play an important role in distribution of growth substances.

### 3.1.5 Morphogenetic effect of chemical factors

Chemical factors also affect morphogenesis in plants. Normally chemical factor are known to execute their effect on physiological processes occurring inside an organism but beside this they do affect form and structure of plant. Till now we have studied about factors such as light, temperature, water, gravity which execute their effect on plant through external environment. But chemical factors influence morphogenesis through external as well as internal environment.

There is another peculiar feature of chemical factors that their effect can be localized to a particular part of plant instead of affecting the whole plant. Effect of chemical substance varies from time to time and from one phase of plant life cycle to another. Different elements are required by living organisms for several physiological functions. Elements such as O, N, K, Mg, C, Ca are considered to be macro elements. Since they are needed in larger amounts on the other hand elements such as B, Cu, Zn, Co, Mn are known as microelements (trace elements) as they are required in micro quantities by living organisms.

Nitrogen is essential constituent of all the proteins. Nitrogen is also reported to enhance growth of plants. In a study conducted by Burkholder and Mc Veigh in maize plant displayed better meristematic growth and enhanced length and diameter of stem when cultivated in presence sufficient quality of nitrogen. Nitrogen is also known to enhance differentiation in phloem with increased growth of sieve tube and vessels. The ratio of C/N is also known to affect morphogenesis. Nitrogen is known to support vegetative growth hence plants having low C/N ratio tends to possess few flowers or fruits. Whereas when the ratio of C/N is high abundant flowering and fruiting occurs. Studies conducted have also related C/N ratio to the ratio of shoot length and root length.

Phosphorus is another element which is a prime constituent of nucleic acid (DNA and RNA). Besides being an important part of DNA and RNA, phosphorus also promotes cell division in roots but has little effect on elongation of stem. If we compare effect of phosphorus to that of nitrogen, elongation of stem is promoted by nitrogen but nitrogen does not directly affect cell division.

Calcium is known to support formation of cell wall. However, calcium is not directly a part of composition of cell wall but it produces its effect by bringing changes in cytoplasm. Zn is a trace element but is known to have an indirect effect on maintaining auxin in its active state. Boron is also required for cell wall formation. Deficiency of Boron causes hypertrophy and hyperplasia of tissue.

Plant hormones better known as plant growth regulators also control and coordinate morphogenesis in plants. Auxin and cytokinin remain to be the most significant plant hormones, along with them ethylene is crucial for fruit ripening, Gibberellic acid for germination. Almost all the morphogenesis response or growth shown by plants is mediated by one or the other hormone.

### 3.1.6 Morphogenetic effect of genetic factor

Genes are known to have specific response to a specific environment. We are very well familiar with George Mendel‟s law of genetics. In his first law called as Law of dominance he described how inheritance of genes governs formation of tall or short plants in *Pisum sativum*. Both types of plant (tall and short) can be easily differentiated from one another based upon their genetic composition. Transcription and translation of genes leads to synthesis of enzymes which directly regulate or control growth and morphogenesis in plants. Generally any morphogenetic trait is not entirely controlled or affected by a single gene but many genes or polygenes collectively affect morphogenesis. One of the key effects of genes on morphology is seen in extent of growth as well as on distribution of growth. Several examples are available where shape of leaves, flowers, fruits is inherited and controlled by gene expression.

Some plants develop perfect or complete flower having both male (staminate) and female (pistillate) flowers. Such flowers are also known as hermaphrodite or bisexual and when male and female flowers develop on the same plant i.e. some flowers will be male and some flowers will be female such plant is called monoecious and the condition is known as monoecism whereas when male and female flowers develop on separate plant as seen in case of animals and the plant is called dioecious and the condition is known as dioecism In this case a male plant will develop only male flowers and female plant will develop only female flowers. Some common example of dioecious is strawberry (*Fragaria*). These types of sexual development in flowers are controlled by specific gene. However, environmental factors equally contribute to development of sex of flowers.

Genes also play a crucial role in production and distribution of growth substances which in turn affects morphology of plant. Genes also control photoperiodic effect which regulates flowering in plants. As a result of gene mutation, the flower time and season may get altered.

Most plant are haploid i.e. two sets of chromosome in each nucleus. In some plants number of sets of chromosome is multiplied. Such plants are called polyploids (triploid with three set of genes, tetraploid with four set of genes and so on). Polyploids plants are believed to exhibits better growth in terms of leaves size, enhanced number and size of fruits and flower etc. But this increase is restricted to certain level only.

**SELF ASSESSMENT EXERCISE**

- Explain the different morphogenetic factors
- How does these factors affect morphogenesis of plants

## 4.0 CONCLUSION

In this unit, Morphogenesis is defined as a process concerned with formation and development of whole plant, a part of plant or a specific structure. This difference develops due to difference in growth pattern, growth rate and different dimension of growth. Different factors called as morphogenetic factors affect growth and development of plants. These factors can be environmental such as light, temperature, water etc, Physical factors and mechanical factors also affect morphogenesis in plants. Beside environmental factor, genetic factor (genes) also control and regulate morphogenesis. Genes are considered to be the ultimate control agent of growth and development. However, genes alone do not control growth instead they interact with prevailing environmental conditions to regulate growth.

## 5.0 SUMMARY

Different factors called as morphogenetic factors affect growth and development of plants. These factors can be environmental such as light, temperature, water etc, Physical factors and mechanical factors also affect morphogenesis in plants. Beside environmental factor, genetic factor (genes) also control and regulate morphogenesis. Light is one of the most crucial factors for growth, development and survival of plants. Light influences flowering, height, strength of stem, development of xylem and phloem etc. Plants also need an optimum temperature for growth and development. However, the optimum temperature may vary from one plant species to another. Physical factors such as compression, tension, bending and swaying, gravity also effect growth and development of plants. Chemical factors also affect morphogenesis in plants. Several elements are required by plants for normal formation and growth of tissues and organs. Nitrogen enhances differentiation in phloem and increases growth of sieve tube and vessels. The ratio of C/N is also known to affect morphogenesis. Phosphorus also promotes cell division in roots. Boron is also required for cell wall formation. Genes remain to be the most crucial factor governing growth and development as they control and regulate complete morphogenesis of plant stating from establishment of polarity, vegetative growth and reproductive growth.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Mention about significance of vernalization in horticulture?
2. On what parameter effect of gravity differs from effect of other morphogenetic factors?
3. Length of photoperiod can also affect sex of plant. Cite a suitable example in support of the statement?
4. Explain the meaning of morphogenetic factors. Mention about different types and function of morphogenetic factors?

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## MODULE 9: EMBRYOLOGY



## UNIT 1: MALE GAMETOPHYTE

### CONTENTS



### 1.0 INTRODUCTION

A living organism cannot survive forever. For existence each species has to continue and for it, each member must reproduce its own kind. Dear students you all know that plants reproduce by asexual, vegetative and sexual means.

Asexual reproduction is the formation of new individuals from the cell/s of single parent. The offspring will be exact genetic copies of the parent except in specific cases of 'automixis'. Asexual reproduction is of various types (fission, sporulation, budding, fragmentation, parthenogenesis) and vegetative propagation is one of asexual reproduction types. Regeneration of plant from any vegetative part of it i.e. stem cutting, rhizome, tuber, bulb, leaves etc. is known as vegetative reproduction/vegetative propagation.

### 2.0 OBJECTIVES

By the end of this unit, you should be able to:

1) Explains the male gametophyte?
2) What do you understand by the term „microsporogenesis"?
3) Is there any difference between the terms sporogenesis and microsporogenesis?

4) What is the process of development of male gametophyte in Angiosperms?

## 3.0 MAIN CONTENTS

### 3.1 Male Gametophyte

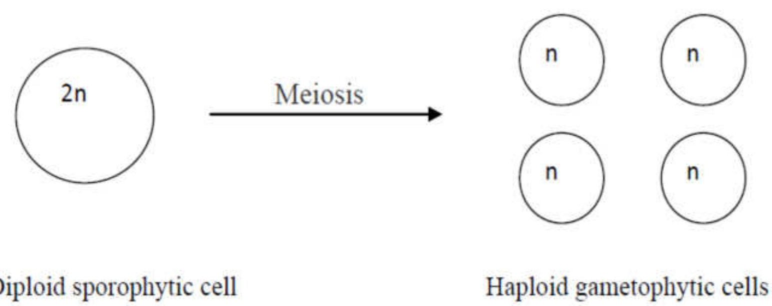
Asexual reproduction including vegetative one is an accessory mean of propagation and do not involve genes from different cell lineages whereas in sexual reproduction, fusion of two dissimilar gametes from two different parents leads to formation of new combination of genes.

If we are talking about the life cycle of flowering plants, it is characterized by an alternation between a dominant sporophytic generation and a highly reduced gametophytic generation. Dominant sporophytic generation is diploid and reduced gametophytic generation is haploid.

The normal sexual cycle (amphimixing) involves two important processes:

1) Meiosis and
2) Fertilization

In meiosis also known as reduction division, a diploid sporophytic cell (SMC; spore mother cell) gets converted into four haploid gametophytic cells. (‘‘2n‟ number of chromosomes becomes half i.e. „n‟ number of chromosome)




In fertilization, two haploid gametes of opposite sex fuse to form diploid sporophytic generation.

So we can say, in a sexual cycle a diploid generation (sporophytic) alternates with a haploid generation (gametophytic).

The major function of diploid sporophytic generation is to produce haploid spores, which are the products of meiosis. Spores undergo cell proliferation and differentiation to develop into gametophytes. The major function of gametophytic generation is to produce haploid gametes.
During the Angiosperm life cycle, the sporophyte produces two types of spores, microspores and megaspores. These spores give rise to male gametophytes and female gametophyte, respectively. The Angiosperm gametophyte develops within sporophytic tissues that constitute the sexual organs of the flower.

The male gametophyte, also referred to as the pollen grain or microgametophyte, develops within the stamen‟s anther and is composed of two sperm cells encased within a vegetative cell (McCormick, 1993, 2004).

The female gametophyte, also referred to as the embryo sac or megagametophyte, develops within the ovule, which is found within the carpel‟s ovary.

In Angiosperms the gametophytic generation is short and is represented by embryo sac (on the female side) and microspores or pollen grains (on the male side). Remaining part of the life cycle is sporophytic generation.The sporophyte eventually produces flowers

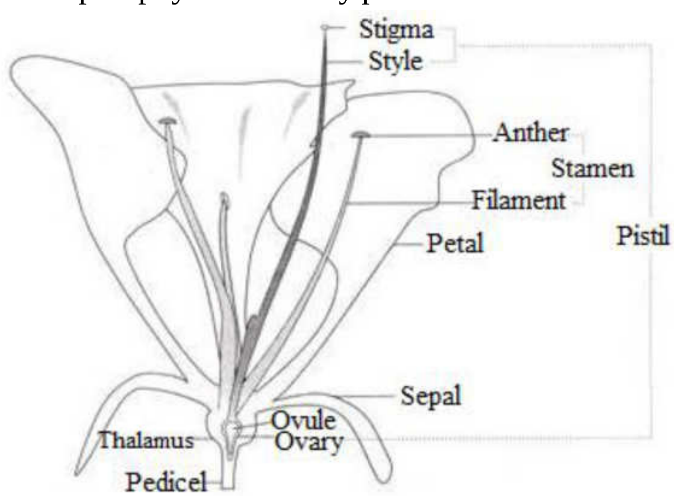



**Fig. 9.1: Flower showing reproductive organs**

Production of spores and formation of gametes are important events in the sexual reproductive cycle that take place in the flower.

The floral organ concerned with male sexual reproduction is the stamen, and the part of the stamen where events of male sexual reproduction occur is the anther. Similarly the floral organ concerned with female sexual reproduction is the pistil (carpel), and the part of the pistil where events of female sexual reproduction occur is the ovule inside the ovary (Fig. 9.1).

Now it is clear to you that Angiosperm plants are diploid sporophytes i.e. spore bearing plants and haploid spores are developed by meiosis or reduction division. The male spores or microspores are developed by meiosis within the microsporangium (pollen sac) while the female spores or megaspores are developed by meiosis within the megasporangium (ovule). These, in their turns, develop the male and the female gametophytes which are endosporous (developing inside the spores).

The process of development of the spore is termed as sporogenesis. When it is microspore (pollen), it is termed as microsporogenesis. When it is megaspore, it is termed as megasporogenesis (Fig. 9.2).

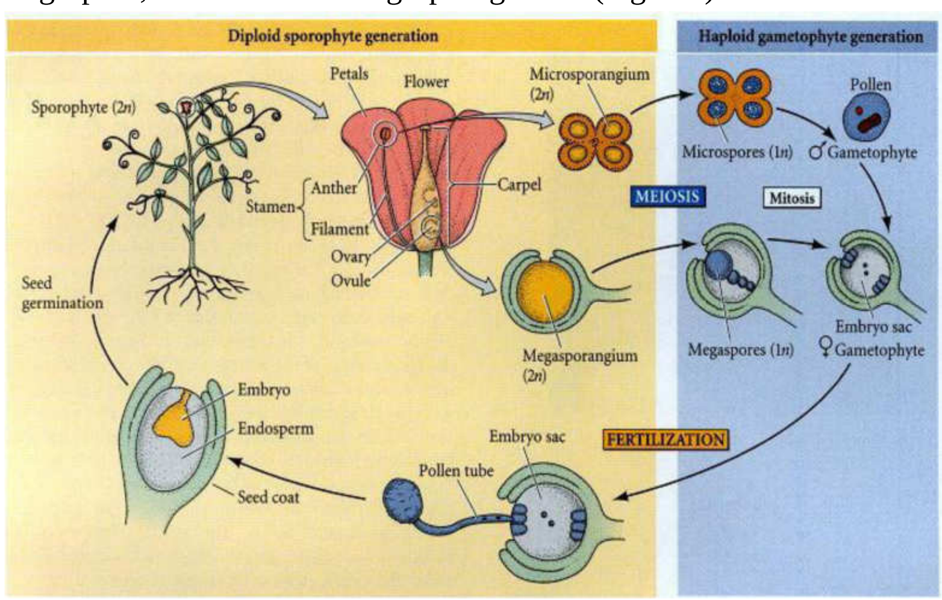



**Fig. 9.2: Life cycle of a typical Angiosperm (example - a pea plant).**

The sporophyte is the dominant generation, but multicellular male and female gametophytes are produced within the flowers of the sporophyte. Cells of the microsporangium within the anther undergo meiosis to produce microspores. Subsequent mitotic divisions are limited, but the end result is a pollen grain. The megasporangium is protected by two layers of integuments and the ovary wall. Within the megasporangium, meiosis yields four megaspores-three small and one large. Only the large megaspore survives to produce the embryo sac. Fertilization occurs when the pollen germinates and the pollen tube grows toward the embryo sac. The sporophytic generation may be maintained in a dormant state, protected by the seed coat

## 3.2 Structure of Anther

The fertile portion of stamen is called anther. Actually the stamen is a slender organ and consists of the proximal sterile part, the filament (stalk) bearing at its distal end a fertile part, the anther. A typical anther has two anther lobes connected by a connective and each anther lobe has two pollen chambers (microsporangia/pollen sacs). Pollen grains (microspores), which contribute the male gametes, are present in each microsporangium or we can say are formed within an anther.

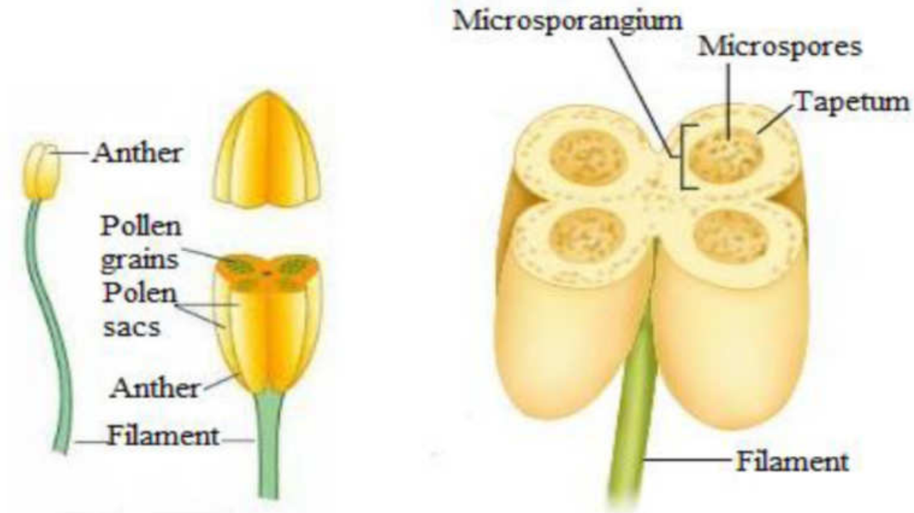



**Fig. 9.3: Stamen showing dithecous anther**

When the anther has two lobes then it is termed as **dithecous** (two lobed) as in *Citrus* having four microsporangia (Fig. 9.3). Sometimes anther may have single lobe instead of two, at this condition anther is termed as **monothecous** (one lobed) as in *Hibiscus rosa-sinensis* having two microsporangia. A young anther comprises a mass of undifferentiated thin-walled cells bounded by epidermis.

Flowers are structures of sexual reproduction. The essential organs of flower are stamens (microsporophylls) - which make the androecium, and carpels (megasporophylls) - which together form the gynoecium or the androecium represents the male reproductive elements of the flower and gynoecium, the female reproductive elements of the flower.

### 3.2.1 Microsporangium (pollen sac/pollen chamber)

The microsporangium is a structure in an anther which produces the microspores and eventually the male gametophyte. A microsporangium or future pollen sac is a cylindrical sac which appears circular in transverse section. It consists of two parts, outer wall and central homogeneous mass of sporogenous tissue. Microsporangial wall has four types of layers:

1) Epidermis (common anther covering)
2) Endothecium
3) 2-3 middle layers and
4) Tapetum

#### 3.2.1.1Development of Microsporangium

During the development of microsporangium, the anther is seen initially as a homogeneous mass of meristematic cells, oblong in cross section and surrounded by a well defined epidermis (Fig. 9.4 A). It then becomes more or less four lobed and in each lobe some hypodermal cells become more prominent than the others because of their larger size, more deeply staining cytoplasm and conspicuous nuclei. These cells constitute the archesporial initials (archesporium) (Fig.9.4 B). There may be only one archesporial cell in each of the four lobes as in *Boerhaavia.* The archesporial cells divide by periclinal division (in a plane parallel to the outer wall of the anther lobe), cutting off primary parietal cells toward the epidermis and primary sporogenous cells toward the interior of the anther. Then the cells of parietal layer forms 2-5 layers of anther wall by undergoing a series of divisions, both periclinal as well as anticlinal. The primary sporogenous cells either directly or after few mitotic divisions functions as microspore mother cells or pollen mother cells (MMCs or PMCs).

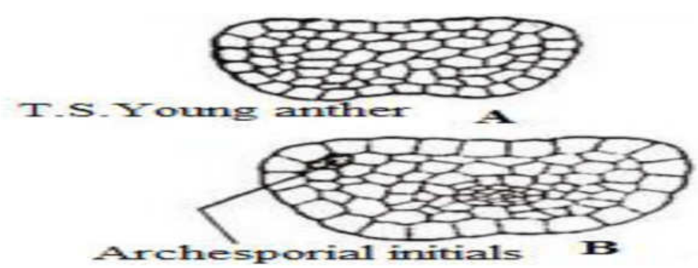



**Fig. 9.4: In cross section anther is showing - A: Homogenous mass of meristematic cells surrounded by epidermis; B: Archesporial initials**

### 3.2 Microsporogenesis

"Microsporogenesis means development of microspores/pollen grains".
The process of development of the microspore (pollen) is termed as microsporogenesis. During microsporogenesis the nucleus of each microspore mother cell or pollen mother cell (2n) undergo meiosis or reduction division, giving rise to four haploid (possessing „n" number of chromosomes) microspores. At the end of meiosis four haploid microspores are enclosed in a common callose wall. The individual spore lacks a wall of its own and it is a callose partition which separates spores from each other. Aggregates of four microspores are called as microspore tetrads. Later on each spore forms its own wall (Fig. 9.5).

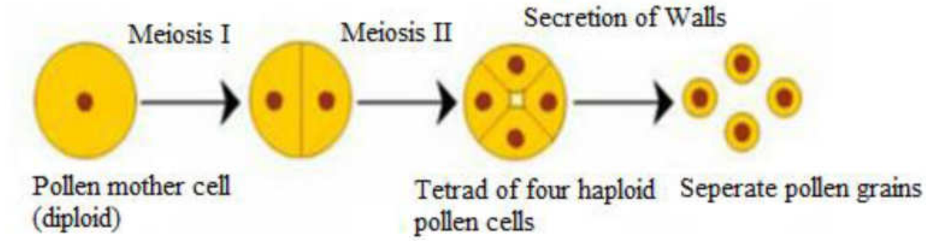



**Fig. 9.5: Microsporogenesis**

### 3.3 Development of Male Gametophyte in Angiosperm

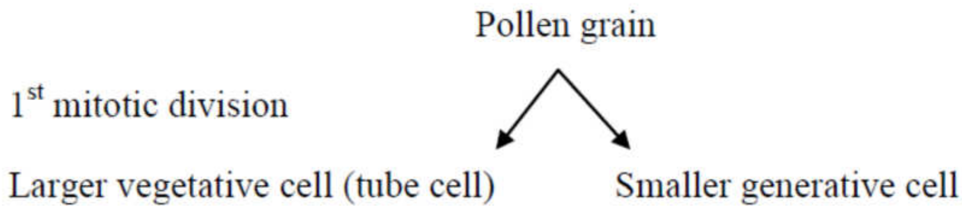
#### 3.3.1 Gametogenesis

Process of development of male gametophyte is known as gametogenesis and haploid microspores or pollens formed from diploid Microspore Mother Cell (MMC) as a result of meiosis are the first cell (mother cell) of male gametophyte. Therefore MMC could be called as last cell of sporophytic generation or sporophyte. Soon microspores released from the tetrad and are referred to as pollen grains.

The development of the male gametophyte is remarkably uniform in Angiosperms. Microspore is the first cell of a male gametophyte. **This cell undergoes only two divisions.** The second division is concerned with generative cell only and this division may take place either in the pollen grain or in the pollen tube. The life of the male gametophyte is very short as compared to that of the sporophyte.

**3.3.1.2Pre-pollination development**

Pollen grains begin to germinate before pollination.
A pollen grain divides mitotically (first division) to form two unequal cells, a smaller generative cell and a larger vegetative cell (also known as tube cell) (Fig. 9.6).




In over 60% of flowering plants, mostly dicots, pollen grains are shed from the microsporangium at 2-celled stage (tube cell + generative cell) for pollination. Generative cell divides after pollination and in the remaining species, pollen grains are shed at 3-celled stage (tube cell + two male gametes). Generative cell divides before pollination.

**3.3.1.3Post-Pollination development**

Once the pollen grain reaches the receptive stigma by means of pollination, it germinates.

On the stigma the compatible pollen grain absorbs water and nutrients from the stigmatic secretion through its germ pores. The tube or vegetative cell enlarges and forms a long slender pollen tube by coming out of the pollen grain through one of the germ pores. It secretes pectinase and other hydrolytic enzymes to create a passage for it in the style if the latter is solid. The pollen tube absorbs nourishment from the cells of the style for its growth.

As the pollen germinates and the pollen tube comes out through the germ pore, the generative cell soon divides mitotically for the second time to form two non-motile sperms (male gametes). This act is known as spermatogenesis. The generative cell or its products, i.e. two male gametes and the tube nucleus migrate into the pollen tube which now represents the mature male gametophyte.

### 3.3.2 Pollination

It is the process of pollen transfer from anther to stigma of a flower. Therefore for pollination the first and very important requirement is the release of pollen grains from the pollen chamber and for releasing pollens anther must dehisce.

**Anther dehiscence**

For dehiscence of anther three types of specialized cells are required- stomium, septum and endothecium. The opening through which the pollen grains are discharged from the pollen sac is called stomium. The septum, that separates the two lobes of an anther, breaks down at a later stage. The cells of endothecium are thin walled along the line of dehiscence of each anther lobe. On maturity of the 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. Mature anther, generally dehisces by means of slit or apical pores.

**SELF-ASSESSMENT EXERCISE**

1) Explains the male gametophyte?
2) Explain the term „microsporogenesis"?
3) Differentiate between sporogenesis and microsporogenesis?

## 4.0 CONCLUSION

In this unit we have discussed the meaning of various terms i.e. gametophyte, male gametophyte, microsporogenesis, etc. and about the structure of anther. We also learnt about the process of microsporogenesis, and various steps of gametophyte development. Alternation of generation is a remarkable aspect of the life cycle of all higher plants. Angiosperm plants are diploid sporophytes i.e. spore bearing plants and the haploid spores are developed by meiosis. In some plants gamete formation takes place after the release of pollen from the anther, it is called „the pollens are shed at the 2-celled stage" while in some plants gamete formation takes place while the pollen are still confined to the anther, it is called „the pollens are shed at the 3-celled stage".

## 5.0 SUMMARY

Gametophyte is the haploid generation producing gametes in plants. Male and female reproductive organs in plants are stamen and carpel, the necessary parts of flower. The male spores or microspores (pollens) are developed by reduction division or meiosis within the microsporangium (pollen sac). Each mother cell undergoes meiosis or reduction division to form four microspores (pollen grains). The process of development of the microspore (pollen) is termed microsporogenesis. The pollen grain or microspore is the first cell (mother cell) of the male gametophyte. Male gametophyte is endosporous i.e. developing inside the spores. At maturity, pollen grains released and through various agents i.e. wind, water, animal etc. reach the compatible stigma (either of the same flower or another). This is known as pollination.

## 6.0 TUTOR-MARKED ASSIGNMENT

1) What is gametogenesis? Explain development of male gametophyte
2) What are the pre-pollination and post pollination steps in male gametophyte development
3) Write explanatory note on development of microsporangium.
4) What do you understand by microsporogenesis. How it occurs?

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## UNIT 2: FEMALE GAMETOPHYTE

## CONTENTS



## 1.0 INTRODUCTION

Life cycle of plants alternate between multicellular haploid gametophyte and multicellular diploid sporophyte and both differ morphologically as well as functionally.

According to Gifford and Foster (1989), in a life cycle of a plant:

- Diploid sporophyte produces haploid spores as a result of reduction division (meiosis).
- Spores develop into gametophytes.
- Gametophytes produce haploid gametes.
- The fusion of female gamete (egg) and male gamete gives rise to the zygote.
- Zygote is the beginning of diploid sporophyte.

When we are talking about the life cycle of Angiosperms:

- Diploid sporophyte produces two types of spores- microspores and megaspores.
- Microspore develops into male gametophyte as discussed in previous unit and megaspore produces female gametophyte which we will study in this unit.

The gametophyte in Angiosperms develops within sporophytic tissue – the sexual organs of the flower. The male gametophyte (developing pollen grain composed of two sperm cells encased within a vegetative cell) develops within the anther, fertile part of the stamen (McCormick, 1993, 2004). The female gametophyte (embryo sac) develops within the ovule which is found within the ovary.

Gynoecium or pistil represents the female reproductive organ in a flower and carpel is a unit of it. A carpel consists of a basal swollen ovary bearing one or more ovules, a receptive stigma, and often a stalk-like style between them (Fig. 9.7). Ovules as you have read, are enclosed by the ovary wall. The part of the carpellary tissue to which the ovules are attached is called placenta and the distribution of ovules in the ovary is described as placentation.

Ovule also known as megasporangium is the place of formation of the megaspores and the female gametophyte. The latter, after fertilization produces the embryo and endosperm, while the entire megasporangium with its enclosed structure becomes the seed and the progenitor of the next generation.

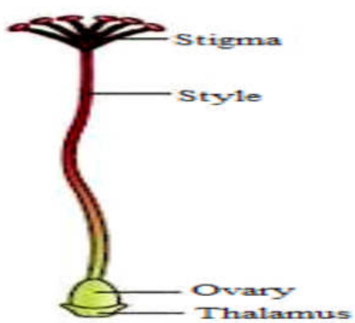


**Fig. 9.7 Gynoecium**

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- What is ovule?
- How many types of ovule are there and on what basis they are differentiated?
- What is megasporogenesis?
- Are all megaspores responsible for female gametophyte formation?

- Is there any difference between female gametophyte or embryo sac?
- Explain *Polygonum* type of embryo sac.

## 3.0 MAIN CONTENT

### 3.1 Structure of Ovule

The megasporangium or ovule consists of nucellus and its protective coats, the integuments. It is attached to the placenta, on the inner wall of ovary by a stalk called funiculus (funicle) and the point of attachment of the body of the ovule to the funiculus is called hilum.

A mature ovule, ready for fertilization, consists of nucellus enveloped almost completely by one or two sheaths, known as integuments, leaving a small opening at the apical end. This opening is known as micropyle. The basal region of the ovule where it is attached to the placenta by funicle, is called chalaza and so this side is known as chalazal end. Its opposite end is termed as micropylar end, the main passage for the entry of the pollen tube into the ovule. In the nucellus, female gametophyte is present, also known as embryo sac.

Nucellar tissue is parenchymatous and represents the wall of the megasporangium. The nucellus is mostly consumed by the developing embryo sac or endosperm. Each ovule has only one nucellus. However, two nuclei may occur as abnormality within a common fold of integuments as has been observed in *Aegle marmelos* (Fig. 9.8).
The ovule with a single integument is called unitegmic, with two integuments is called bitegmic and without integument is called ategmic.

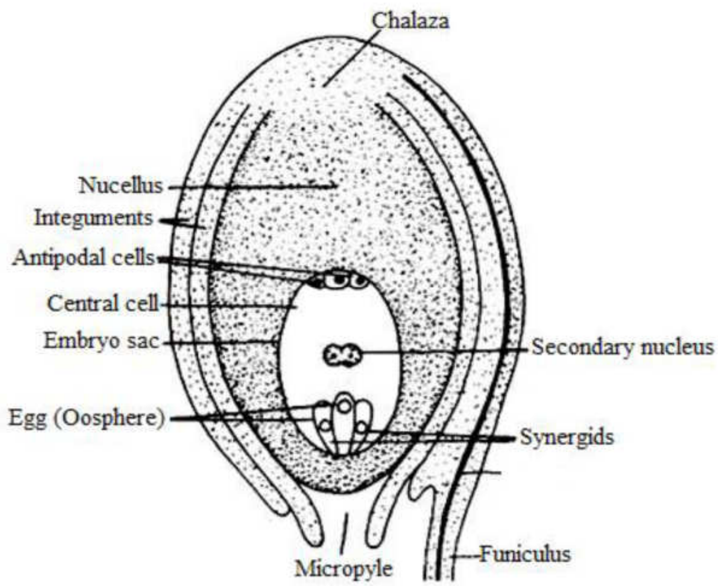


**Fig. 9.8: Structure of ovule**

### 3.1.1 Parts of the ovule:

1. Funiculus or Funicle: A stalk by which ovule is attached to the placenta
2. Nucellus: the body of ovule
3. Integument: the protective covering of nucellus
4. Micropyle: small opening formed by two integuments over nucellus
5. Chalaza: basal part of the ovule
6. Hilum: region where ovule fuses with funiculus
7. Embryo sac: female gametophyte located in the nucellus, developed from megaspore

### 3.1.2 Types of ovule

On the basis of the position of the micropyle with respect to the funiculus, mature ovule can be classified into six main types. These are:

1. Orthotropous
2. Anatropous
3. Campylotropous
4. Amphitropous
5. Hemianatropous
6. Circinotropous

Depending on the extent of development of the nucellus and on the basis of position of sporogenous cell, ovule can also be categorized as:

1. Tenuinucellate type
2. Crassinucellate type

- **Tenuinucellate type**: The archesporial cell directly functions as the megaspore mother cell so that the sporogenous cell is also hypodermal. Such ovules, where the sporogenous cell is hypodermal and the nucellar tissue around it remains single-layered, are called **tenuinucellate**.
- **Crassinucellate type**: The hypodermal archesporial cell divides transversely, forming outer parietal cell and an inner sporogenous cell. The parietal cell may either remain undivided or undergo a few divisions (both periclinal as well as anticlinal) so that the sporogenous cell becomes embedded in the massive nucellus. The sporogenous cell may be embedded in the massive nucellus by divisions in the nucellar epidermis. All such ovules where the sporogenous cell becomes subhypodermal, by either above two means, are called **crassinucellate**.

## 3.2 Development of Ovule

The ovule at first arises as a primordium on the placenta in the cavity of the ovary. Later due to meristematic activity of the cells of ovular primordia, the protuberance become prominent and grows into a mass of tissue, the nucellus. The initials of two integuments arise at the base of the nucellus. The inner integument which is usually formed first, initiates from the epidermal layer and the outer integument is initiated either dermally or subepidermally. With the differentiation of integuments the ovule begins to curve and by the megaspore tetrad stage it assumes its final shape. Although the integuments initiate later they grow faster than the nucellus. The integuments soon cover the nucellus, leaving a small opening at the tip, the micropyle.

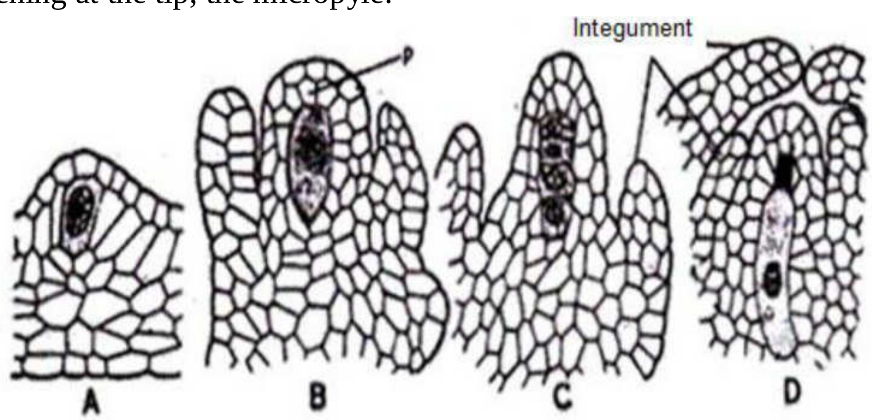


**Fig. 9.9: Stages of ovule development and megasporogenesis. A. Protuberance of placental tissue and differentiation of**

**archesporium (shaded); B. Parietal cells and megaspore mother cell (shaded). One integument is developing; C. Linear tetrad of megaspores (shaded); D. Disintegration of the three upper megaspores and enlargement of the functional megaspore. Both integuments have developed.**

Female gametophyte development occurs in two phases:

1. Megasporogenesis
2. Megagametogenesis

The developmental pattern exhibited by most species is referred to as the *Polygonum* type because it was first described in *Polygonum divaricatum* (Strasburger, 1879; Maheshwari, 1950).

### 3.2.1 Megasporogenesis

"Development of the megaspore within the ovule (megasporangium) is known as megasporogenesis."

A hypodermal cell in the nucellus (at the micropylar end) differentiates and functions as the archesporium (archesporial cell). It is distinguishable from the other cells as it becomes more prominent than its surrounding cells due to its large size, dense cytoplasm and large nucleus.

As it is now clear to you from the previous section that ovule can be categorized into two types (tenuinucellate and crassinucellate), on the basis of position of sporogenous cell. So here in tenuinucellate type of ovule, the archesporial cell directly functions as megaspore mother cell (MMC) and in crassinucellate type of ovule the archesporial cell do not directly behave as MMC and instead of that it divides periclinally into two cells. An outer primary parietal cell (towards epidermis) and an inner primary sporogenous cell. Now this primary sporogenous cell functions as the megaspore mother cell.

Megaspore mother cell is also known as megasporocyte having diploid (2n) chromosome number. It undergoes meiosis i.e. reduction division. As a result of this four haploid megaspores are formed. After first meiotic division, the wall is laid down transversely, forming a dyad. The second meiotic division in the two dyad cells is also transverse. In this way a row of four haploid megaspore cells (linear tetrad) is formed. Meanwhile, two integuments develop from the base of the ovule.

**Functioning megaspore**

During megasporogenesis, the diploid megaspore mother cell undergoes meiosis and gives rise to four haploid nuclei. Angiosperms exhibit three main patterns of megasporogenesis, referred to as monosporic, bisporic, and tetrasporic. The three types differ mainly in whether wall (cell plate) formation occurs after these divisions, thus determining the number of meiotic products that contribute to the formation of the mature female gametophyte.

**Pollination**

Dear students after reading male gametophyte unit and this unit about female gametophyte, you should have learnt by now that male gamete is contained within the microspore which develops as male gametophyte while the female gamete (egg) is contained within the female gametophyte which is the embryo sac develops within the megaspore and is located within the megasporangium or ovule. So the next biological phase is pollination.

You are also familiar about the term pollination which means the transfer of the pollen from the anther to the receptive stigma whether of the same flower or of a different flower.

Based on the destination of pollen grains, two types of pollinations are there:

1) Self-pollination: If the pollen is transferred from anther to the stigma of the same flower, it is called self pollination or autogamy as in pea, wheat and rice. When the pollen of one flower pollinates the stigma of different flower, but on the same plant, it is called geitonogamy.
2) Cross-pollination: If the pollen is transferred from anther to the stigma of the another flower, it is called cross pollination or allogamy as in hemp and willow. Cross pollination within a species (may be inter-varietal) is termed as xenogamy.

Pollination leads to fertilization and production of seeds and fruits which ensure continuity of plant life.

**Agents for pollination**

Pollination process can occur by different agencies which can be classified into two categories:

1) Abiotic such as wind (anemophily or anemophilous) and water (hydrophily or hydrophilous) and
2) Biotic such as insects (entomophily or entomophilous), birds (ornithophily or ornithophilous), and bats (cheiropterophily or cheiropterophilous).

**SELF ASSESSMENT EXERCISE**

- What is ovule?
- How many types of ovule are there and on what basis they are differentiated?
- What is megasporogenesis?
- Are all megaspores responsible for female gametophyte formation?

## 4.0 CONCLUSION

In this unit we have discussed the structure of ovule, types of ovule on the basis of the position of the micropyle with respect to the funiculus, as well as on the basis of dependency on the extent of development of the nucellus and on the basis of position of sporogenous cell. Further development of ovule along with megasporogenesis, female gametophyte development with particular reference to *Polygonum* type was described. After development of male and female gametophyte, the next biological phase is pollination, which is must for fertilization. Pollination means the transfer of the pollen from the anther to the receptive stigma whether of the same flower (self-pollination) or of a different flower (cross pollination). Abiotic (wind and water) and biotic (insects, birds and bats) agents are responsible for pollination. On the basis of these agents pollination may be anemophilous (by wind), hydrophilous (by water), entomophilous (by insects), ornithophilous (by birds) and chiropteriphilous (by bats). Pollination ends in a copious dusting of the stigma surface with pollen grains.

## 5.0 SUMMARY

The whole unit is summarized in the following key points:

- Gametophyte is the haploid generation producing gametes in plants.
- When we are talking about female then it is said to be female gametophyte.
- The female gametophyte (embryo sac) develops within the ovule which is found within the ovary.
- A carpel consisting of a basal swollen ovary bearing one or more ovules, a receptive stigma, and often a stalk-like style between them.
- Ovule consists of nucellus surrounded by integuments.
- Ovule, on the basis of the position of the micropyle with respect to the funiculus, is of 5 types - Orthotropous, Anatropous, Campylotropous, Amphitropous, Hemianatropous.
- Ovule depending on the extent of development of the nucellus and on the basis of position of sporogenous cell, is of 2 types - tenuinucellate and crassinucellate.
- Female gametophyte (embryo sac) located in the nucellus, developed from megaspore.
- Female gametophyte development occurs in two phases - megasporogenesis and megagametogenesis
- The process of development of the megaspores is termed megasporogenesis.
- The female spores or megaspores are developed from MMC by reduction division or meiosis within the megasporangium (ovule).
- The functional megaspore now forms the female gametophyte (embryo sac).
- Development of the female gametophyte is completely endosporous means within the megaspore.
- During megagametogenesis, the functional megaspore gives rise to the mature female gametophyte.
- After development of male and female gametophyte, the next biological phase is pollination, which is must for fertilization.

- Pollination means the transfer of the pollen from the anther to the receptive stigma whether of the same flower (self-pollination) or of a different flower (cross pollination). Abiotic (wind and water) and biotic (insects, birds and bats) agents are responsible for pollination.

## 6.0 TUTOR-MARKED ASSIGNMENT

Briefly discuss the history of Crop Physiology base on the following headings;

1. State the different types of ovule.
2. Explain the patterns of megasporogenesis and megagametogenesis in Angiosperms.
3. “Agents of pollination”, throw light on this sentence

## 7.0 REFERENCES/FURTHER READING

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## UNIT 3: FERTILIZATION AND POST FERTILIZATION

### CONTENTS



### 1.0 INTRODUCTION

In this unit we will discuss about fertilization and post fertilization developments along with some very important phenomena occurring in the life cycle of Angiosperm plants i.e. apomixis, adventive embryony, polyembryony and parthenocarpy.

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

In Angiosperms fertilization initiates with the compatible type pollen (male gametophyte) reaching the stigma and ends with the fusion of male and female gametes in the embryo sac (female gametophyte). The pollens received by the female reproductive organ i.e. gynoecium are held at the stigma.

There is no such way by which the pollen (male gamete) can reach to the egg (female gamete) in the embryo sac. So to overcome this difficulty pollen germinate on the stigma and forms pollen tube which penetrate the stigmatic tissue, grows down the style, enters the ovary and finally finds its way into the embryo sac (female gametophyte) through ovule. Here it releases two sperms (male gametes) in the vicinity of the female gametes. Out of the two sperms, one fuses with the egg (syngamy) and forms zygote. The other one fuses with the polar nuclei or the secondary nucleus (triple fusion) and forms primary endosperm nucleus. This phenomenon is known as double fertilization and is a characteristic unique feature of the Angiosperms. After series of divisions primary endosperm nucleus forms endosperm, endosperm is very nutritive tissue that nourishes the developing embryo. Zygote or oospore forms embryo, either dicotyledonous or monocotyledonous embryo, as the case may be.

## 2.0 OBJECTIVES

By the end of this unit, you should be able to:

- What is fertilization?
- About the different ways of entry of pollen tube into the ovule.
- What is syngamy?
- What do you understand by triple fusion?
- What comes in post fertilization developments?
- Also become familiar with terms like apomixis, parthenogenesis etc. What is polyembryony and on what basis it can be classified into different types?
- Define parthenocarpy.

## 3.0 MAIN CONTENTS

### 3.1 Fertilization

“Fertilization is the process of fusion of two dissimilar reproductive units, called gametes.” In flowering plants, the process of fertilization was first discovered by Strasburger in 1884. As described earlier, the female gametophyte (embryo sac) of Angiosperms is situated in the ovule, at a distance from the stigma. There is no such device developed in the gynoecium (pistil) which facilitates transfer of pollen from stigma to embryo sac. Therefore the pollen after reaching to the stigma produces a pollen tube which facilitates transport of male gametes deep into the embryo sac from stigma.

**In Angiosperms, the fertilization is being completed as follows:**

- **Germination of pollen grains and growth of pollen tube**

When the pollen is shed from anther it has usually two cells:

1) A generative cell
2) A vegetative cell (tube cell)

The generative cell forms two male gametes. Once the pollen has landed on compatible receptive stigma as a result of pollination, its germination starts. On the surface of stigma the pollen hydrates. This means pollen absorbs water from the surrounding and swells. After that the vegetative cell forms a pollen tube. The stigmatic fluid secreted by the stigma contains sugars, lipids and resins, etc. which provides suitable medium for the germination of pollen grains. Pollen grains as well as pollen tube contain an enzyme cutinase which helps in the penetration of pollen tube into the stigmatic tissue. Cutinase as the name indicates degrades the cutin of the stigma at the point of contact with the pollen tube. The entire content of the pollen including two male gametes of generative cell move into the pollen tube (Fig. 9.10).

The growing pollen tube penetrates the stigmatic tissue and pushes its way through the style and then down the wall of the ovary. The style may be hollow or solid. If it is hollow, then the pollen tube grows along the epidermal surface but in case of solid style, the pollen tube travels through intercellular spaces between the cells which lie in its path.

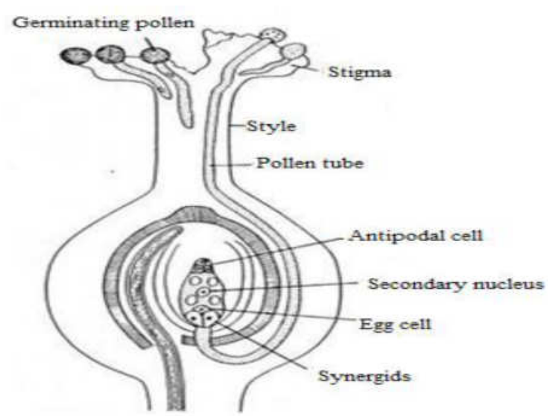



**Fig. 9.10: Longitudinal section of a flower showing growth of pollen tube**

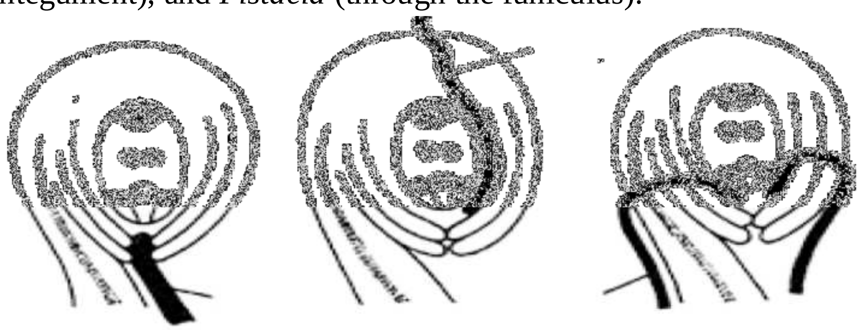
### 3.1.1 Entry of pollen tube into ovule

After arriving in the ovary, the pollen tube finds its way into the ovule. The pollen tube may enter into the ovule via three routes;

1. Through the micropyle
2. Through the chalazal end
3. Through the integument

On that basis of modes of entry and place of pollen tube into the ovule, three terms are given as follows:

a) Porogamy: When the pollen tube enters the ovule through the micropyle, the condition is known as porogamy. This is the most common mode of pollen tube entry into the ovule and so the most common type of fertilization.
b) Chalazogamy: When the pollen tube enters the ovule through the chalazal end, the condition is known as chalazogamy. This type of pollen tube entry into the ovule and so the type of fertilization is observed in *Casuarina*, *Betula* and *Juglans regia*. The chalagogamy was first reported by Treub (1891) in *Casuarina*.
c) Mesogamy: When the pollen tube enters the ovule through the integument or through the funiculus, the condition is known as mesogamy. This type of pollen tube entry into the ovule and so the type of fertilization is observed in *Cucurbita* (through the integument), and *Pistacia* (through the funiculus).



Porogamy Chalazogamy Mesogamy

**Fig. 9.11: Modes of entry of pollen tube into the ovule**

### 3.1.2 Entry of pollen tube into the embryo sac

It does not matter through which way pollen tube enters into the ovule; it always enters in the embryo sac from the micropylar end means entry of pollen tube in the embryo sac is irrespective of pollen tube entry into the ovule (Fig. 9.11). Again the entry of pollen tube into the embryo sac after passing micropyle may be via different passages. It may be:

1. Between the egg cell and one of the synergids e.g. *Fagopyrum*
2. Between the wall of the embryo sac and one or other synergids.er. *Cardiospermum*
3. Directly penetrates one of the synergids e.g. *Oxalis*

So we can say that synergids not only play an important role in determining the entry of pollen tube in the embryo sac but they also affect dissemination of male gametes in the embryo sac.

### 3.1.3 Discharge of male gametes from pollen tube

After reaching the embryo sac the pollen tube burst at its tip and deliver the (two) male gametes. Just prior to bursting of pollen tube the tube nucleus disorganizes. Immediately after releasing, the male gametes show amoeboid movement and one male gamete moves toward the egg and other one move to the polar nuclei (Fig. 9.12).

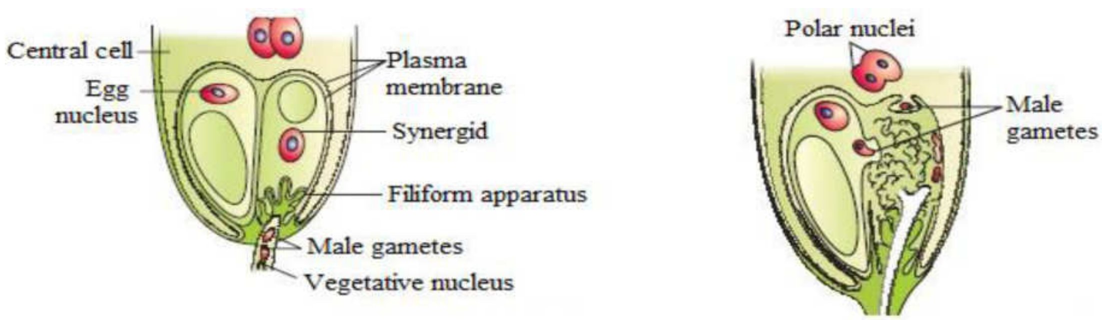



**Fig.9.12: A: Enlarge view of an egg apparatus showing path of pollen tube growth; B: discharge of male gametes into a synergid and the movement of the male gametes, one into the egg and the other into the central cell**

### 3.1.4 Syngamy- fusion of gametes

As the one of the male gametes reached the egg, it fuses with it. As a result of this fusion diploid zygote/oospore (2n) forms (because you know the egg and the male gamete, both are haploid). The fusion of male and female gametes is known as fertilization. This is also known as syngamy. One of the most significant discoveries was made by Strasburger in 1884, as mentioned above. He observed the actual fusion of the male gamete with the female gamete (egg) in *Monotropa*.

Since two male gametes are released by the pollen tube, what happened to the second male gamete? The answer was provided by S. G.Nawaschin (1898). He showed that the one male gamete fused with the egg (syngamy) and the other male gamete with the polar nuclei (triple fusion) while working with Fritillaria and Lilium. So this was the discovery of double fertilization.

## 3.2 Post Fertilization Developments

After fertilization, development of the embryo and the endosperm within the ovule goes side by side. The oospore (zygote), formed as a result of fusion of one male gamete with the egg, develops into the embryo while the primary endosperm nucleus- product of triple fusion, develops the endosperm. The other nuclei or cells within the embryo sac (synergids, antipodal cells) disorganize sooner or later.

### 3.2.1 Development of the Endosperm

The primary endosperm nucleus is a product of triple fusion. This undergoes a series of divisions and ultimately forms endosperm. The Angiospermic endosperm is a triploid (3n) tissue as it is a product of triple fusion. It is formed either by the fusion of one haploid male gamete and one diploid secondary nucleus (fusion product of two haploid polar nuclei) or by the fusion of three haploid nuclei (one male gamete belongs to male gametophyte and two polar nuclei belongs to the female gametophyte).

It is therefore distinct from the endosperm of heterosporous Pteridophytes and Gymnosperms where the endosperm is a simple haploid (n) tissue of the gametophyte not involving any triple fusion like in Angiosperms. Endosperm is a highly nutritive tissue which provides nourishment to the developing embryo.

Depending upon mode of development three types of endosperm has been recognized:

1. Nuclear endosperm
2. Cellular endosperm
3. Helobial endosperm

Of these nuclear endosperm is the most common type which occurs in about 56% families of Angiosperms. It is followed by cellular endosperm (reported in 25% families of Angiosperms) and then by helobial endosperm (reported in 19% families of Angiosperms).

1. **Nuclear endosperm**

In this type of endosperm the division of primary endosperm nucleus and number of subsequent nuclear divisions are not accompanied by wall formation and the nuclei thus produced remain free in the cytoplasm of the embryo sac. They remain in the peripheral layer of the cytoplasm surrounding a large central vacuole. Wall formation occurs at later stage around nuclei. The wall formation is mostly centripetal i.e. from the periphery towards the centre and usually begins from the basal periphery e.g. *Arachis hypogea*.

In some cases the central vacuole may not be filled up even in the mature seed. This is seen in the palms. *Cocus nucifera* is the classical example of this type of nuclear endosperm. Development of endosperm in it deserves special mention. The primary endosperm nucleus undergoes a number of free nuclear divisions. Then the embryo sac gets filled with a clear fluid (watery liquid endosperm) in which numerous nuclei float. It is known as liquid syncytium. Gradually nuclei start settling at the periphery with the beginning of peripheral cell wall formation. This forms the coconut meat. In mature coconuts the liquid endosperm becomes milky. The watery endosperm of coconut contains growth promoting „coconut milk factor" and that is why it is used as a nutrient medium in plant tissue culture experiments. Nuclear endosperm is commonly found in polypetalous dicotyledons (Fig. 9.13).

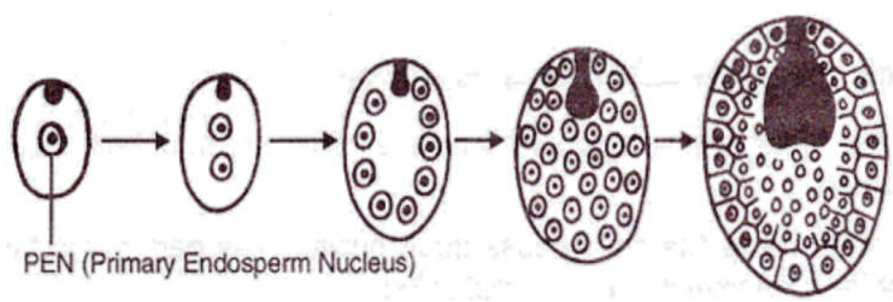



**Fig.9.13: Nuclear endosperm formation**

2. **Cellular endosperm**

In this type of endosperm, division of the primary endosperm nucleus is immediately followed by wall formation so that the endosperm is cellular from the beginning. The first wall is laid down transversely but the subsequent divisions are irregular. *Adoxa, Peperomia, Villarsia* etc. are some common examples (Fig.9.14).

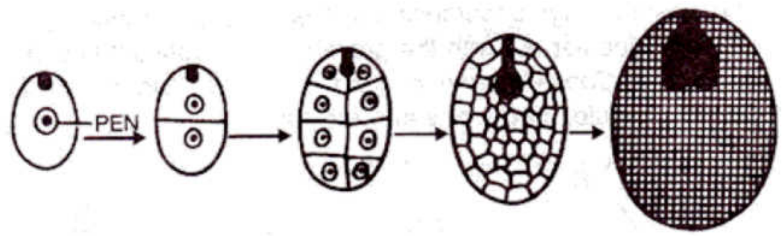



**Fig.9.14: Cellular endosperm formation**

3. **Helobial endosperm**

Among members of Helobiales (e.g. *Vallisneria, Eremurus, Limnophyton* etc.) there is type of endosperm the development which is intermediate between the nuclear and the cellular type. Here the first division of the primary endosperm nucleus is accompanied by the formation of transverse wall. This divides the embryo sac unequally into two compartments - a small chalazal chamber and a large micropylar chamber. This step is followed by free nuclear division in both the chambers but there are relatively more free nuclear divisions in micropylar chamber in comparison to chalzal one. The chalazal chamber often degenerates. The free nuclear divisions in the micropylar chamber are followed by wall formation and thus a cellular endosperm tissue is formed and usually found in the members of the order Helobiales (Fig.9.15).

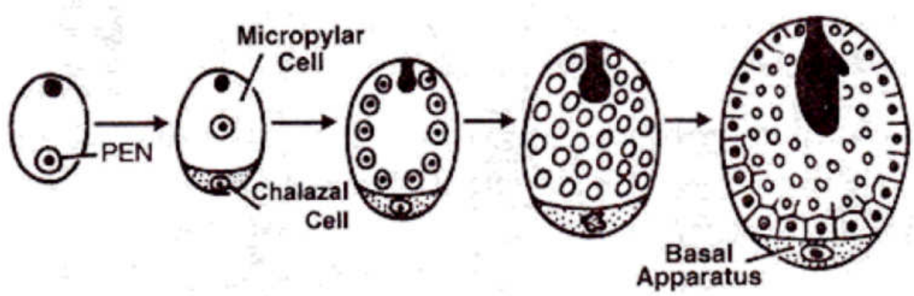



**Fig.9.15: Helobial endosperm formation**

### 3.2.2 Development of the embryo

After fertilization, a series of changes occurs in the ovule and finally seed is formed. Side by side with the development of the endosperm, the oospore (zygote, the fertilized egg) is developing the embryo after a period of rest.

The process of development of mature embryo from diploid oospore is called embryogenesis.

Both dicotyledons and monocotyledons begin embryo development in the same way but there is considerable difference in later differentiation. Before proceeding let us discuss about the dicotyledonous and monocotyledonous embryo.

The dicotyledonous embryo as the name reflects, has two cotyledons attached laterally to an embryonical axis, whereas in the monocotyledonous embryo, the embryonical axis has a single cotyledon at its apex. Due to this organographic difference, it is very easy to distinguish the two types of embryo but there is no fundamental difference in their early stage of development. The development is very similar till the globular stage.

In all Angiosperms the embryogenesis starts with the division in oospore and it divides to develop a two-celled proembryo by forming a transverse wall. The cell near the micropyle is termed the basal cell and the cell facing towards the centre of the embryo sac is called the terminal cell. The basal cell forms the suspensor and may or may not contribute in rest activities so sometimes called as suspensor cell, whereas terminal cell is responsible for further development of embryo so called embryo cell.

### 3.2.3 Types of embryo development

On the basis of plane of division of the terminal cell (also known as apical or embryo cell) in the 2-celled proembryo and the contribution of the basal cell and terminal cells in the formation of embryo proper, six types of embryogeny (embryo development) have been reported by Johansen (1950) among the Angiosperms. They are;

1. **Onagrad or Crucifer type** (e.g. Annonaceae, Brassicaceae, Onagraceae, Pedaliaceae, Ranunculaceae, Scrophulariaceae).
2. **Asterad type** (e.g. Asteraceae, Balsamianceae, Violaceae, Vitaceae).
3. **Solanad type** (e.g. Campanulaceae, Linaceae, Solanaceae, Theaceae).
4. **Caryophyllad type** (e.g. Caryophyllaceae, Crassulaceae,Haloragaceae).

5. **Chenopodiad type** (e.g. Boraginaceae, Chenopodiaceae).
6. **Piperad type** (e.g. Loranthaceae, Piperaceae).

## 3.3 Apomixis

“Reproduction without fertilization”

Apomixis in flowering plants is defined as the asexual formation of a seed from the maternal tissues of the ovule, avoiding the processes of meiosis and fertilization, leading to embryo development.
The term Apomixis was first coined by Hacke in 1893. Apomixis, derived from two Greek word "Apo" (away from) and "mixis" (act of mixing or mingling). Winkler (1908) explained the term apomixis as the substitution of sexual reproduction (amphimixis) by any such method which does not involve meiosis and syngamy or we can say that Winkler used the term apomixis to signify any asexual method of propagation not involving the normal production of embryo by fertilization. It includes even propagation by bulbils.

The first discovery of this phenomenon is credited to Leeuwenhoek as early as 1719 in *Citrus* seeds. When we are talking about asexual formation of seed, in this sense apomixis is synonymous with agamospermy: seed formation without fertilization of the egg cell. In some plants meiosis [which converts a diploid sporophytic cell into four haploid gametophytic cells] and fertilization [where two haploid gametes of opposite sex fuse to re-establish the diploid sporophytic generation], the two very important necessary processes of sexual cycle (amphimixis) are interrupted. Even then a viable embryo if formed resulting into asexual seeds. When these asexual seeds produce plants identical to the female parent are called apomictic seeds and the phenomenon is known as apomixis.
The plants showing apomixis are known as apomictic plants. It is most common in Poaceae, Asteraceae, Rosaceae and Rutaceae.
When apomixis is the only method of reproduction in a plant species, it is known as obligate apomixis. When gametic and apomictic reproduction occurs in the same plant, it is known as facultative apomixis.
Apomixis is of the following types as suggested by Maheshwari (1954):

i) Non-recurrent apomixes: Non-recurrent means which cannot be repeated. In this type of apomixis, the megaspore mother cell undergoes normal meiotic division and one of the four megaspores thus formed develops into haploid female gametophyte (i.e.

embryo sac). However, there is no fertilization and the embryo arises directly from normal egg-cell (n). Since an egg cell is haploid, the resulting embryo will also be haploid and so sterile, therefore the process cannot be repeated in the next generation.

Haploid parthenogenesis (the embryo develops from the unfertilized egg) and haploid apogamy (the embryo develops from some other cell of the embryo sac like antipodal cell or synergid cell) are non- recurrent apomixis. Such types of apomixis are of rare occurrence.

ii) Recurrent apomixes: Recurrent means which can be repeated. In recurrent apomixis, the nuclei of the embryo sac are usually diploid. Such embryo sac may arise either from a cell of the archesporium due to disturbance in meiosis (generative apospory) or from some other cell of the nucellus due to disintegration of megaspore mother cell (somatic apospory).

The embryo subsequently develops directly from the diploid egg-cell without fertilization. Somatic apospory, diploid parthenogenesis and diploid apogamy are recurrent apomixis. However, diploid parthenogenesis/apogamy occurs only in aposporic (somatic) embryo-sacs.

iii) Adventive apomixes**:** In it, the development of embryo takes place from any diploid cell of the ovule lying outside the embryo sac. Since it takes place outside the embryo sac, it is not grouped with recurrent apomixis, though this is regenerated with the accuracy. In addition to such embryos, regular embryo within the embryo sac may also develop simultaneously, thus giving rise to polyembryony condition as in *Citrus, Opuntia.*

iv) Vegetative apomixes: In some cases like *Poa bulbosa* and some *Allium, Agave* and grass species, vegetative buds or bulbils, instead of flowers are produced in the inflorescence. They can also be reproduced without difficulty. However, Russian workers do not group this type of vegetative reproduction with apomixis.

Apomixis does not involve meiosis, so there is no segregation and recombination of chromosomes. Therefore it could be useful in preserving desirable characters for indefinite period.

### 3.3.1 Parthenogenesis

Parthenogenesis means development of an embryo directly from an egg cell or a male gamete or it may be defined as - the development of female gamete into a new individual without fertilization. Parthenogenesis may be haploid or diploid as the case may be.

i) **Haploid parthenogenesis**: Generally, normal haploid egg develops into an embryo, so the embryo and resultant plant are haploid. This type of parthenogenesis is termed as haploid parthenogenesis e.g. *Oenothera, Datura*. Plants thus produces are sterile.

ii) **Diploid parthenogenesis**: When the cells of embryo sac including egg cell are already diploid as a result of apospory. This diploid egg when develops parthenogenetically into diploid embryo, termed as diploid parthenogenesis e.g. *Taraxacum*.

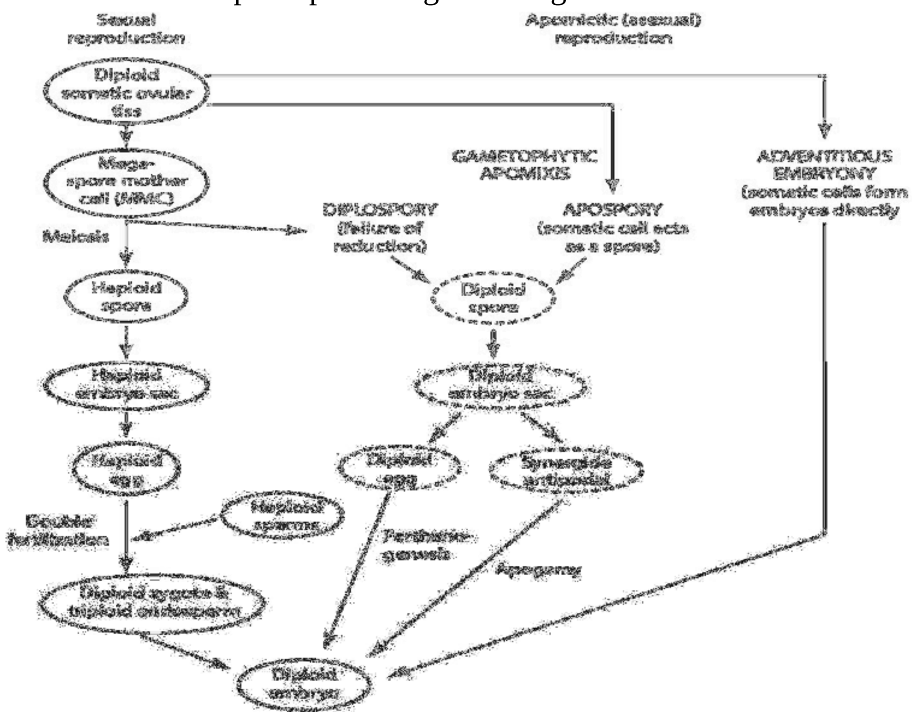



**Fig. 9.16: Diagrammatic representation of embryo formation through different ways**

### 3.4 Polyembryony and Parthenocarpy

After fertilization, ovules mature into seeds. In normal case, a single embryo is present in each seed but sometimes more than one embryo may present in a seed. When a seed contain more than one embryo, this condition is termed as polyembryony. Therefore, polyembryony has been defined by many workers as the occurrence of more than one embryo in a seed or "The development of several embryos within the same ovule."

Polyembryony is very common among Gymnosperms but when we are talking about Angiosperms, it is very rare. You can find it in *Citrus* species like lemons, oranges (Fig.9.17) and also in few *Quercus* species. Additional embryos do not always mature. They may degenerate during the course of development. The mature seed thus has only one embryo. The first case of polyembryony was reported by Antoni van Leeuwenhoek in 1719 in certain orange seeds. Since then it has been observed in large number of plants.

**Fig.9.17: Multiple seedlings grow from a single mandarin orange seed as the result of polyembryony**

### 3.4.1 Classification of Polyembryony

In broad sense it is of two types:

i) Spontaneous- includes instances of naturally occurring polyembryony.

ii) Induced- includes instances of experimentally induced polyembryony.

Ernst (1901, 1910) divides spontaneous polyembrony into two categories:

i) True polyembryony- development of two or more embryo in same embryo sac

ii) False polyembryony - development of embryos in more than one embryo sac within the same ovule

There are number of factors responsible for polyembryony in Angiosperms and they are:

1) Cleavage of proembryo
2) Formation of embryos by cells of the embryo sac other than the egg
3) Development of more than one embryo sac within the same ovule
4) Activation of some sporophytic cells of the ovule

On the basis of these above factors the following four types of polyembryony have been recognized in Angiosperms (Braun, 1859).

1) Cleavage polyembryony resulted due to cleavage or splitting of the proembryo.
2) Embryos from cells of the embryo sac other than the egg.
3) More than one embryo sac in the same ovule.
4) Activation of some sporophytic cells of the ovule.

### 3.4.2 Parthenocarpy

The term was introduced by Noll (1902). According to him, parthenocarpy means the development of fruits without pollination or any other stimulus.

According to present concept- “Parthenocarpy is the formation of fruits without fertilization” (Nitsch, 1965). Therefore the fruits which develop without fertilization are called parthenocarpic fruits and the phenomenon is described as Parthenocarpy.

On the basis of requirement of pollination stimulus, it can be categorized into two categories:

i) **Stimulative parthenocarpy:** In this type the parthenocarpic development of fruit may require the pollination stimulus.

ii) **Vegetative parthenocarpy:** In this type the parthenocarpic development of fruit may occur in unpollinated flowers.

Nitsch (1963) had recognized three types of parthenocarpy:

1) Genetic
2) Environmental
3) Chemically induced

- **Genetic parthenocarpy**

When many of the plants cultivated for their fruits show seeded as well as parthenocarpic varities. This type of parthenocarpy is known to arise due to either mutations or hybridization. Example- Seedless navel oranges, *Citrus, Cucurbita, Musa*, *Punica* and *Vitis.*

- **Environmental parthenocarpy**

Variations in environmental conditions such as frost, fog, temperature interfare with the normal functioning of sexual organs and causes parthenocarpy. Example- Seedless olives due to heavy fog (Campbell, 1912), pears due to freezing temperature for 3-19 hours (Lewis, 1942).

- **Chemically induced parthenocarpy**

Plant growth regulators like auxins and gibberellins have been successfully use to induce parthenocarpy in a number of plants which normally bear seeded fruits e.g. parthenocarpic tomato, blackberry, strawberry, figs, *Citrus* etc.

**SELF ASSESSMENT EXERCISE**

- What is fertilization?
- About the different ways of entry of pollen tube into the ovule.
- What comes in post fertilization developments?

- Also become familiar with terms like apomixis, parthenogenesis etc. What is polyembryony and on what basis it can be classified into different types?
- Discuss parthenocarpy.

## 4.0 CONCLUSION

In this unit we have discussed about fertilization, pathway of pollens to their destination for fertilization. After that we have also learnt post fertilization development process. Along with these topics light have been thrown on apomixis, adventives embryony, polyembryony as well as on parthenocarpy.

## 5.0 SUMMARY

Summary of all the topics covered in this unit is given in the following key points:

- Once the pollen grain reaches the receptive stigma, as a result of pollination, it germinates producing a long slender pollen tube. Two male gametes and the tube nucleus migrate into the pollen tube which now represents the mature male gametophyte.
- Pollen tube penetrates the stigmatic tissue and pushes its way through the style and then down the wall of the ovary.
- After arriving in the ovary, the pollen tube may enter into the ovule through micropyle (porogamy), through chalazal end (chalazogamy) or thrugh integuments (mesogamy).
- Irrespective of the route of the entry of the pollen tube into the ovule, it always enters the embryo sac from the micropylar end.
- After entering into the embryo sac, the tip of the pollen tube bursts and the two male gametes are released.
- Out of the two male gametes one male gamete fuses with the egg nucleus and result in the formation of zygote or oospore (2n). Second male gamete fuses with two polar nuclei, resulting into primary endosperm nucleus (3n). This phenomenon is termed as double fertilization.
- After series of divisions primary endosperm nucleus forms endosperm. Endosperm is very nutritive tissue that nourishes the developing embryo.
- Zygote or oospore forms embryo.

- On the basis of plane of division of the terminal cell in the 2-celled proembryo and the contribution of the basal cell and terminal cells in the formation of embryo proper, six types of embryogeny (embryo development) have been reported by Johansen (1950) among the Angiosperms i.e. Onagrad or Crucifer, Asterad, Solanad, Caryophyllad, Chenopodiad and peperad types.
- Reproduction without fertilization is referred as apomixis.
- Development of several embryos within the same ovule is known as polyembryony.
- Parthenocarpy is the formation of fruits without fertilization.

## 6.0 TUTOR-MARKED ASSIGNMENT

1. Define briefly the endosperm development in *Cocos nucifera*.
2. Describe in detail the post fertilization developments and explain the development of different types of endosperms in Angiosperms.
3. Types of embryo development.
4. Define different types of apomixes and classify polyembryony.

## 7.0 REFERENCES/FURTHER READING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