PREFACE

With its grounding in the "guiding pillars of Access, Equity, Equality, Affordability and Accountability," the New Education Policy (NEP 2020) envisions flexible curricular structures and creative combinations for studies across disciplines. Accordingly, the UGC has revised the CBCS with a new Curriculum and Credit Framework for Undergraduate Programmes (CCFUP) to further empower the flexible choice based credit system with a multidisciplinary approach and multiple/ lateral entry-exit options. It is held that this entire exercise shall leverage the potential of higher education in three-fold ways – learner's personal enlightenment; her/ his constructive public engagement; productive social contribution. Cumulatively therefore, all academic endeavours taken up under the NEP 2020 framework are aimed at synergising individual attainments towards the enhancement of our national goals.

In this epochal moment of a paradigmatic transformation in the higher education scenario, the role of an Open University is crucial, not just in terms of improving the Gross Enrolment Ratio (GER) but also in upholding the qualitative parameters. It is time to acknowledge that the implementation of the National Higher Education Qualifications Framework (NHEQF), National Credit Framework (NCrF) and its syncing with the National Skills Qualification Framework (NSQF) are best optimised in the arena of Open and Distance Learning that is truly seamless in its horizons. As one of the largest Open Universities in Eastern India that has been accredited with 'A' grade by NAAC in 2021, has ranked second among Open Universities in the NIRF in 2024, and attained the much required UGC 12B status, Netaji Subhas Open University is committed to both quantity and quality in its mission to spread higher education. It was therefore imperative upon us to embrace NEP 2020, bring in dynamic revisions to our Undergraduate syllabi, and formulate these Self Learning Materials anew. Our new offering is synchronised with the CCFUP in integrating domain specific knowledge with multidisciplinary fields, honing of skills that are relevant to each domain, enhancement of abilities, and of course deep-diving into Indian Knowledge Systems.

Self Learning Materials (SLM's) are the mainstay of Student Support Services (SSS) of an Open University. It is with a futuristic thought that we now offer our learners the choice of print or e-slm's. From our mandate of offering quality higher education in the mother tongue, and from the logistic viewpoint of balancing scholastic needs, we strive to bring out learning materials in Bengali and English. All our faculty members are constantly engaged in this academic exercise that combines subject specific academic research with educational pedagogy.We are privileged in that the expertise of academics across institutions on a national level also comes together to augment our own faculty strength in developing these learning materials. We look forward to proactive feedback from all stakeholders whose participatory zeal in the teaching-learning process based on these study materials will enable us to only get better. On the whole it has been a very challenging task, and I congratulate everyone in the preparation of these SLM's.

I wish the venture all success.

Professor Indrajit Lahiri
Vice-Chancellor

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Four Year Undergraduate Degree Programme

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Course Type: Disciplinary Specific Elective (DSE)
Course Title: Plant Anatomy and Embryology
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1st Print:___________, 2025
Print Order: (memo no. and date)

Printed in accordance with the regulations of the University Grant Commission –Distance Education Bureau

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Unit 1: Tissue and Tissue System

Structure

1.0 Objective

After studying this unit learner will get a complete idea related to meristematic tissue can easily be understood. Knowledge regarding shoot and root apical meristem along with the categorization of meristematic tissue are achieved.

1.1 Introduction

Tissues are said to be groups of cells, which are all alike in origin, structure and function. These may be classified into three groups—such as meristems or meristematic tissue, permanent and secretory tissue.

Meristematic tissue is a group of cells which divide constantly and produce new cells indefinitely through out the plant life. The new cells are formed by division giving rise to permanent tissue by growth and differentiation. So, meristems brings about growth in thickness of the stems and roots of dicotyledonous and gymnospermic groups of plants. Shoot apex, root apex, leaf primordia, vascular cambium in the stem of dicotyledons, cork cambium etc. are the examples of meristems.

Meristematic cells are isodiametric, compactly arranged with little intercellular spaces. All the meristematic cells are with large prominent nuclei, dense cytoplasm with small vacuoles scattered throughout the cytoplasm or altogether absent. Plastids remain in proplastid stage. Walls are usually thin and the cells lack reserve food materials. The cambium cells are usually fusiform and their radial walls are thick. The secondary meristem, phellogen, may contain reserve food materials and ergastic substances. The vascular meristem occur in cambium cells.

Normally at the root and shoot apices the meristematic tissue is very much common. Generally here all the cells are similar in structure and function and such type of meristem is called primordial meristem or promeristem.The primordial or promeristem soon differentiated into protoderm, procambium and ground meristem or otherwise termed as dermatogen, periblem and plerome.

Meristems have been classified variously based on characters like, stage of development, position in plant, origin, function and topography.

1.2 Meristem

A. Meristem based on stage of development

Promeristem is the region of growth in plants. It is usually situated at the apices of roots or stems. Here, all the cells are alike. Promeristem is sometimes also known as primordial meristem, unmeristem, and embryonic meristem.

B. Meristem based on position in plant body

(i) **Apical meristem**: These occur at the apices of roots and shoots of vascular plants. These are also called ‘growing points.’ The length of the organs increases due to the activity of these meristems.

(ii) **Intercalary meristems**: These are formed by the growth of permanent tissues in the intervening apical meristem here and there. They occur in between the masses of permanent tissues as in the internodes of grasses.

(iii) **Lateral meristem**: These meristems occupy the lateral position of plants, and the cells mainly divide periclinally. Growth or increase in diameter of roots and stems occurs through these meristems. Vascular cambium and phellogen belong to this category.

C. Meristem based on origin

(i) **Primary meristem**: When a single cell begins to form a new multicellular plant and starts dividing, the compact group of cells which first appears is known as the "primary meristem." It occupies the growing region and is responsible for the primary growth of plants. Epidermis, cortex, and primary vascular tissues are the derivatives of these meristems, and they remain at the apices of stems and roots, primordia of leaves, and appendages.

(ii) **Secondary meristem**: This develops from primary permanent tissues during the secondary growth of stems and roots in dicotyledons, e.g., interfascicular cambium.

D. Meristem based on function:

(i) **Protoderm or future epidermis**: It is the outermost layer of meristematic cells which forms the epidermis.

(ii) **Procambium or provascular tissues**: This is the tissue of elongated cells that forms primary vascular tissues.

(iii) **Ground or fundamental meristem**: The cells are in a small group and form ground tissue and pith. The cells are usually larger, living, and thin-walled, forming the hypodermis, cortex, pith, etc.

E. Meristem based on plane of cell division

(i) **Mass meristem**: Here, the meristematic cells divide in all planes and thus produce a mass of tissues. Sporangia, endosperm, pith, and cortex are examples of mass meristem.

(ii) **Plate meristem**: Meristematic cells of this category divide only in two planes and thus the cells increase in area like a plate. Examples of this meristem are the growth of the leaf blade, uniseriate epidermis, etc.

(iii) **Rib meristem**: Cells of this meristem divide only in one plane and thus columns or rows of cells are produced. The increase in length of the organ is concerned and takes place by this meristem. The formation of pith and cortex of young roots and stems are examples of this meristematic activity.

1.3 Root Apical Meristem

In the root apex, cells are undifferentiated, and thus, cells are arranged in a pattern characteristic of a species known as the root apical meristem. Cells of the root apical meristem are densely protoplasmic with large nuclei, actively dividing. Electron microscopic study reveals certain vacuoles, and it consists of initial cells from which all tissues of mature roots are derived. The root apex is simpler, producing no lateral organ at the tip. It is subterminal in position, covered by more vacuolated cells of the root cap. Organisation of the root apical meristem is more or less uniform due to the absence of lateral organs.

The tissues of the mature root are eventually derived from the group of cells, which comprise the apical meristem of the primary root. The apical meristem of the root produces cells not only towards the axis but also away from it, which initiates the root cap. Due to the presence of the root cap, the root meristem is not terminal but subterminal in its position. The root branches are usually initiated beyond the region of most active growth, and they develop endogenously. Due to the absence of nodes and internodes, the root grows more uniformly in length than the shoot.

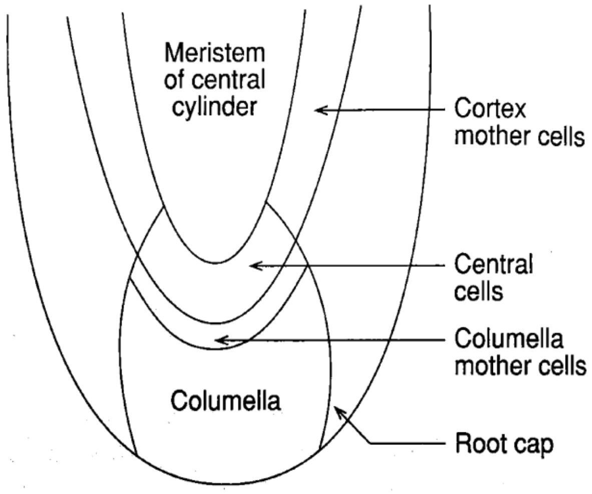


Fig. 1 Diagrammatic representation of the root apical meristem showing different zones. (Redrawn after Mauseth, 1988)

1.3.1 Description of Root Apical Zones (Fig.1)

A. Apical Cell Theory

This theory was developed by Nägeli (1878). In *Dryopteris*, there is a single apical cell from which all the cells of the root apical cell are derived.

B. Histogen Theory

Hanstein (1868) proposed the histogen theory, which was supported by Strasburger (1868). According to this theory, the main body of the plant develops from a mass of meristem of considerable depth. This mass of meristem consists of three cell-initiating layers, known as histogens. Hanstein opined that histogens arise from separate sets of initials and give rise to dermatogen, periblem, and plerome.

(i) **Dermatogen** is the outermost uniseriate layer. Cells of this zone generally divide by radial walls and give rise to the epidermis. In a few cases, the cells of this layer divide by tangential as well as radial walls, giving rise to multiple epidermis, as in *Ficus* leaf.

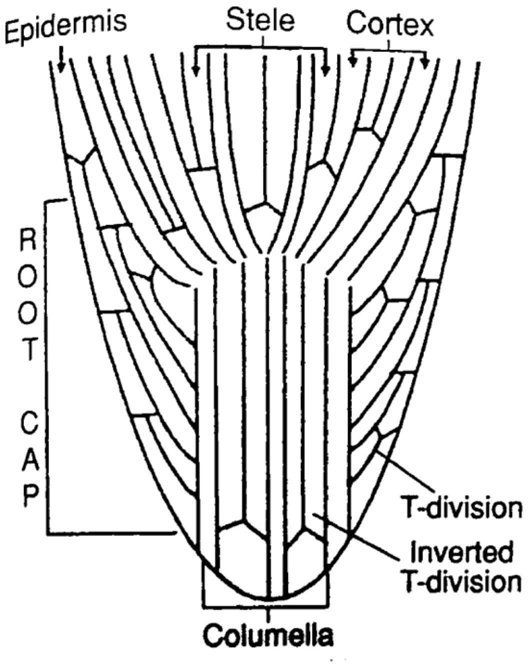
(ii) **Periblem** is lying between the dermatogen and plerome. This zone is constituted of isodiametric cells. Cells of this zone divide actively and give rise to the primary cortex. The endodermis is also derived from periblem.

(iii) **Plerome** is the massive central core of the axis. Cells of this zone divide in all directions and give rise to the pith and vascular cylinder.

The terms dermatogen, periblem, and plerome, as used today, have a somewhat different meaning from those used by Hanstein. Fahn (1967) suggested using the derivatives of promeristems as protoderm, meristem of cortex, and meristem of vascular cylinder instead of dermatogen, periblem, and plerome, respectively.

1.3.2 Root Apex of Angiosperms

According to Guttenberg (1960), the angiospermic root apex consists of three groups of temporary initials, which lie close to the centrally situated permanent initial.



2: Diagrammatic representation showing the root apex meristem according to the Körper-Kappe theory

These three groups form the meristems of the root apex. One group produces the meristem of the cortex. The protoderm and root cap develop from the last group of temporary initials. This type of root axis is noted in *Brassica*, a dicotyledonous plant. In monocotyledonous plants like *Zea mays*, *Triticum aestivum*, etc., there are three groups of temporary initials. But here, the protoderm and root cap develop from separate initials. One group of initials produces the meristem of the vascular cylinder, and the other gives rise to the protoderm and meristem of the cortex. The third or last group of initials forms only the root cap. The special initials of the root cap are termed **calyptrogen**.

1.3.3 Körper-Kappe Theory (Fig.2)

This theory was proposed by Schüepp (1917). According to this theory, the root apex consists of the outer **Kappe** and the inner **Körper** zone. It is based on differences in the planes of cell division. The theory states that the cells in the root apex divide in a pattern called **'T'-divisions**.

Cells of the **Kappe** region initially divide horizontally. The lower daughter cell then divides longitudinally, i.e., at right angles to the plane of the first division. Thus, the planes of the two divisions form a 'T' in a median longitudinal section of the root. The inner region of the apex is the **Körper**. In this inner region, the **'T' is inverted (⊥)**, i.e., the second division takes place in the upper daughter cell. This type of division has been found among the members of **Poaceae** and **Fagaceae**.

1.4 Quiescent Centre

It was observed by Clowes (1958 & 1976) that a group of cells between the root cap and the active meristematic zone in the root apex of *Zea mays* is present. These groups of cells appear in the shape of a hemisphere or disc, and they have very low mitotic activity and synthesize DNA very slowly. These inactive or passive cells constitute the **quiescent centre** and are regarded as temporary initials.

The cells on the periphery of this hemispherical or cup-shaped region are meristematic and may be regarded as the constituents of the **promeristem**. Through various techniques, the existence of the quiescent centre has now been demonstrated in the root apices of a considerable number of species.

According to Clowes (1958, 1976), the quiescent centre develops during the ontogeny of the root. Roots with a single apical cell do not have any quiescent centre. Clowes was able to show that there was a **central region, i.e., the quiescent centre in the roots of *Zea*, where the cytoplasm had a lower content of RNA and the cells had smaller nucleoli**. Moreover, the cells in the quiescent centre did not actively synthesize DNA.

The **physiological and cytological properties** of these cells have been studied in a number of species. The cells in this region have a **lower concentration of DNA, RNA, and protein** than any other cells in the root apex. According to Clowes, the cells of the **quiescent centre also have fewer mitochondria, little cytoplasmic reticulum, and the smallest dictyosomes, nuclei, and nucleoli**. These are less sensitive to radiation damage than the other cells of the meristem.

According to Clowes, cells of the quiescent centre divide during certain periods, especially during the formation of secondary roots or after the root has been damaged. **Cells below the quiescent centre are active and give rise to the root cap.**

1.5 Promeristem

Clowes (1961) defined the **promeristem** as the part of the root apex that is capable of giving rise to all the tissues of the root. The promeristem is situated terminally in the root apical meristem and below the root cap. The promeristem consists of a **single cell in cryptogams but consists of a group of initials in flowering plants**.

1.6 Shoot Apical Meristem

The **shoot apex** is considered the **terminal part of the shoot**, situated immediately above the **uppermost leaf primordium**. In the growing region of the terminal bud, all **primary tissues** are derived from this meristem, which also produces **lateral organs** like **leaf and bud primordia**. That is why its development depends on these lateral outgrowths.

Leaf primordia are produced in a **particular pattern and sequence** below the shoot apex, and it is here that many structural characteristics of the plant are determined. The **time and space interval** between the initiation of two successive primordia is termed **plastochron**. Within one plastochron, the **size and shape of the apical zone** change.

At this stage, the **rate of cell division and other biochemical activities** also change considerably. The periodic changes in the meristem can be seen best in **opposite-leaved forms**.

Like the **root apex**, **shoot apices** have also been described in different **theories**, which are stated below (**Fig. 3**):

1. Apical Cell Theory

According to **Nägeli (1878)**, a **single tetrahedral apical cell** of the **shoot apex** produces other cells. This is observed in **Cryptogams**.

2. Histogen Theory

Introduced in **1870** by **Hanstein**, this theory considers that the **primordial meristem** is sharply **divisible into three distinct zones** or **histogens**. According to this theory, the **apical meristem** or **growing region** of the **stem** is composed of a **small mass of cells**, all of which are **similar** and in a **state of division**. These **meristematic cells** constitute the **promeristem**. Soon, the **promeristem** differentiates into **three regions**:

- **A) Dermatogen**: The **single outermost layer** of cells, which later gives rise to the **epidermis** of the stem.
- **B) Periblem**: Found **internal** to the **dermatogen**, this is the **middle region** of the **apical meristem**. It is **single-layered** at the apex but becomes **multilayered** in the central part. It later develops into the **cortex**.
- **C) Plerome**: Located **internal** to the **periblem**, this is the **central meristematic region** of the **stem apex**. Cells of the **plerome zone** are composed of **thin-walled, isodiametric cells**. Ultimately, it develops and differentiates into the **central stele**, consisting of **primary vascular tissue** and **ground tissues** such as **pericycle, medullary rays, and medulla**.

3. Tunica-Corpus Theory

This theory was proposed by **Schmidt (1924)**. According to this theory, there are **two zones of tissues** in the **apical meristem**, termed **Tunica** and **Corpus**:

- **Tunica** consists of **peripheral layers of cells**, which **divide anticlinally** (perpendicular to the surface).
- **Corpus** consists of **central cells**, where division occurs **in all planes**.

However, in **gymnosperms (except Gnetales)**, there are **no surface layers dividing anticlinally**, leading many researchers to raise objections to this theory.

The **Tunica-Corpus theory** has significantly contributed to the **understanding of meristematic patterns** in the **shoot apices of seed plants**. It has improved knowledge regarding the **position, number, and behavior** of the **initiating cells** in **seed-plant stems**, as well as the **early development stages** of the **primary body of the shoot**.

4. Cytohistological Zonation

Popham (1951) described **seven types** of **shoot apices** based on **cytohistological studies** and their reaction to different stains.

Based on **structure and development**, **Popham** distinguished **three main types** of **gymnosperm shoot apex**, namely: **Cycas type**, **Ginkgo type**, **Cryptomeria-Abies type** (**Fig. 3**)

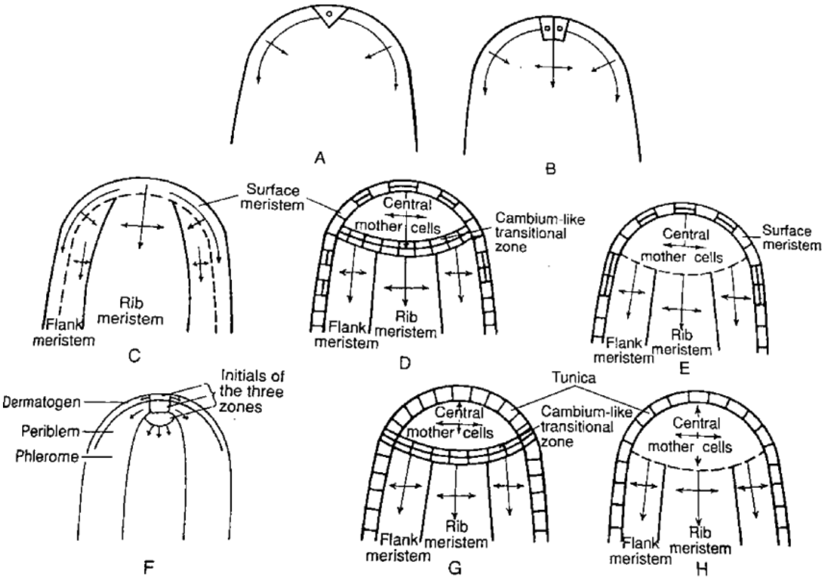


Fig.3: Diagrammatic representation of the shoot apices showing the histological zonations : A. Single apical cell in pteridophyte. B. *Selaginella* type with – 5 apical initials. C. *Cycas* type. D. *Ginkgo* type. E. *Cryptomeria-Abies* type. F. Diagram showing the histogen concept in angiosperm shoot apex. G. *Op ntiau*type. H. General angiosperm type. { Adapted from Fahn (1982)}

In *Cycas* type there are three meristematic zones. In case of *Ginkgo* type there are five meristematic zones and in case of *Cryptomeria-Abies* type—four meristematic zones are distinguished.

In angiosperms Popham suggested two principally recognisable types of corpus based on internal arrangement such as *Opuntia* type and usual angiosperm type.

In usual angiosperm type three main zones can be distinguishable in the corpus and in case of *Opuntia* type an additional cambium-like transitional zone can be distinguished.

(5) Buvat hypothesis : According to Buvat (1952, 1955) central cells of the apex promeristem sponge and promeristem recepticular together called meristemed attente (waiting meristem) and has without histogen. Cell in meristemed attente seldom divide and equivalent to quiescent centre of root apex. Anneau initial (initiating ring) functions during vegetative growth in production of fotiage leaves, the sepals and even the petals.

(6) Common scheme of description of shoot apex : Popham and Chan (1950) used the term ‘mantle’ instead of tunica because in tunica cells divide anticlinally but other division also observed here. This mantle is usually stratified and each stratum is termed as L1, L2 etc. The cells of central part have larger nuclei and less dividing and this zone is known as apical initial group. Below this mantle there lies a distinct zone. Here the cells are less cytoplasmic, vacuolated and more or less isodiametric and less dividing and these cells are termed as central mother cells. Next to this zone is central meristem (C.M.) known as rib meristem. The central derivatives are densely stained from flame meristem or peripheral meristem. In between central meristem (C.M.) cells and

flame meristem there lies a zone where cells have parallel alignment — called as 'cambium like zone' and this zone is considered to be transition between central meristematic cells and central meristem. But some were of the opinion that this zone is not transitional and this zone is situated within central meristem and the cells do not divide on both sides of cambium and termed. This zone is active as nodal ring. According to some this zone is actually rapidly dividing zone just below the youngest apical node.

1.6.1 Dynamic Aspect of Shoot apex

On the basis of function and activity of the apical meristem Newman (1961) redescribed shoot apex. According to him no cell has a permanent initial and it functions temporarily and then uses temporary initial cells. He termed them as 'continuing meristematic residue' (C.M.R.). Newman classified vegetative shoot apex into three types as follows :

(a) Monoplex : This type is found in many vascular cryptogams. Here there is only one initial which divides periclinally.

(b) Simplex : It is found in most gymnosperms. In this case the apex is composed of several initials in one cell layer. The initials divide by periclinal and anticlinal walls.

(c) Duplex : It is Found in angiosperms. Here several initals are present at the apex in more than one layer. The cells i.e., initials of the surface layer divide anticlinally while cells of the innner layer or outer layer may divide more than one plane.

1.7 Summary

After completing this unit the knowledge of meristematic tissues have been achieved, which will be helpful to ascertain the nature of root and shoot apical meristem in different group of plants. Theories of structural development and differentiation of root apex as well as shoot apex gives better understanding for the organization of root and shoot apices.

1.8 Questions

1. Define meristems and classify meristem based on different characters.
2. Define root apical meristems and describe root apical zones as stated in different theories.
3. Describe tunica corpus theory and state the cytohistological zonation in shoot apex. Write down the dyamanic aspect of shoot apex.

1.9 Answers

1. See article no.1.2
2. See articleno.1.3
3. See articleno.1.6

Unit 2: Tissue: Simple and Complex

2.0 Objective

After reading this unit learner will be get a complete idea about the the categorization of meristematic tissue and permanent tissues. Learners will able to describe the nature and function of various simple as well as complex tissues.

2.1 Introduction

A tissue is defined as a continuous organised mass of cells with common origin, structure and function. A tissue may consist of cells of different structures and even different functions, but the cell composition of cells is always the same in tissues consisting of different cell types.

According to Esau (1965), tissues may be defined as ‘‘an organisation of cells into more or less specialised complexes.’’ On the other hand, Fahn (1982) defined tissue ‘‘as a complex of cells of common origin.’’

From the study point of view, the tissues may be categorized into two principal groups as (1) Meristem or meristematic tissue and (2) Permanent tissue.

Permanent tissues are those in which growth has ceased either completely or for the time being. Sometimes they again become meristematic partially or wholly. The cells of these tissues may be living or dead and thin-walled. The thin-walled permanent tissues are generally living, whereas the thick-walled tissues may be living or dead. The cells of these tissues have relatively smaller nuclei and quite distinct vacuoles.

Permanent tissues may further be classified into simple and complex tissues.

2.1.1 Simple tissues

Simple tissues consist of a single type of more or less uniform cells performing similar functions and thus are homogeneous in nature. They are usually of the following types:

1. **Parenchyma**:
   The parenchyma cells form continuous tissue in the cortex of stems and roots and in the leaf mesophyll. They also occur as vertical strands and rays in vascular tissues. They are primary in origin in the cortex, pith, and leaf, and primary or secondary in vascular tissues. Parenchyma cells are characteristically living cells, capable of growth and division. The cells vary in shape, are often polyhedral but may be stellate or much elongated (Fig. 4). Their walls are often primary, but secondary walls are not uncommon. Parenchyma is concerned with photosynthesis, storage of various materials, wound healing, and the origin of adventitious structure. Normally, the parenchyma consists of isodiametric oval or round cells with intercellular spaces. Sometimes when the cells of parenchyma are exposed to light, they develop chloroplasts and the tissue is known as chlorenchyma. In aquatic plants, a special type

of parenchyma is developed which possesses large intercellular air spaces among the cells and is known as aerenchyma. It helps in withstanding the considerable mechanical stress in an aquatic environment. Few parenchyma cells contain leucoplasts. Parenchyma cells also serve to store reserve materials in vacuoles, or in the form of solid particles or liquid in the cytoplasm. Some specialised parenchymatous cells, which contain oils, tannins, crystals of calcium oxalate, etc., are termed as idioblasts. Idioblastic parenchyma cells differ from their neighbouring cells in size, contents, and function.

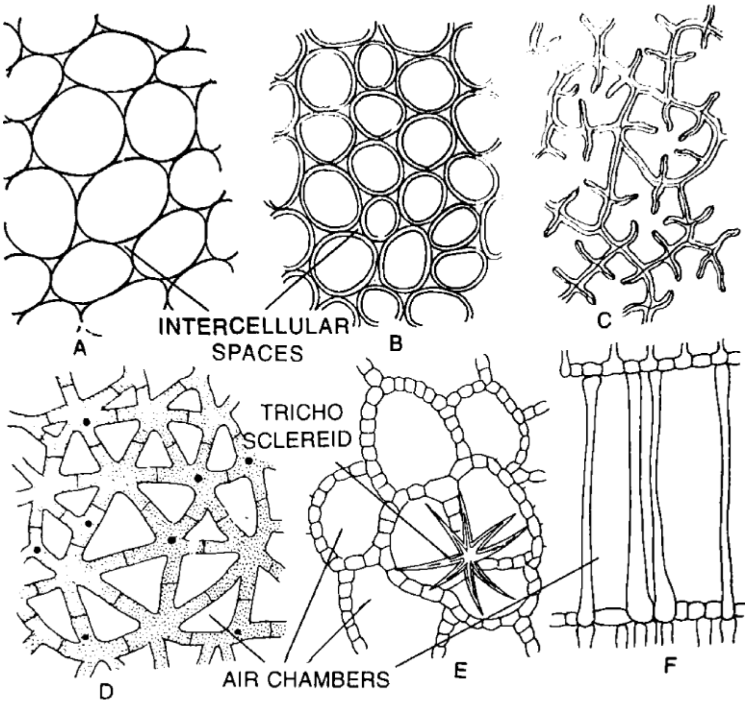


Fig.4: Parenchyma tissue. A—Thin-walled parenchyma. B—Thick-walled parenchyma. C—Parenchyma in the mesophyll of *Pinus* needle. D-F—Different forms of aerenchyma: E—Petiole of *Musa* sp. Petiole of *Nymphaea* sp. F—Stem of *Jussiaea* sp.

2. **Collenchyma** : This is a living tissue composed of living, slightly elongated cells which have generally unevenly thickened cellulosic walls (Fig. 5). Cells of collenchyma are extensible, with a considerable degree of plasticity and high percentage of water. Mature collenchyma cells are less plastic, harder and more brittle than young collenchyma cells. Collenchyma cells may contain chloroplasts and carry out photosynthesis. They also contain tannins. The structure and arrangement of collenchyma cells in the plant body indicate that the primary function of tissue is support. Collenchyma cells occur in a stand or continuous cylinder near the surface of the cortex in stems and petioles and along the veins of foliage leaves, uncommon in roots. Collenchyma cells are usually regarded as a form of parenchyma specialized as supporting tissue in young organs. The shape of cells varies from short prismatic to much elongated one. According to Esau (1965) collenchyma is commonly interpreted as a thick walled type of parenchyma.

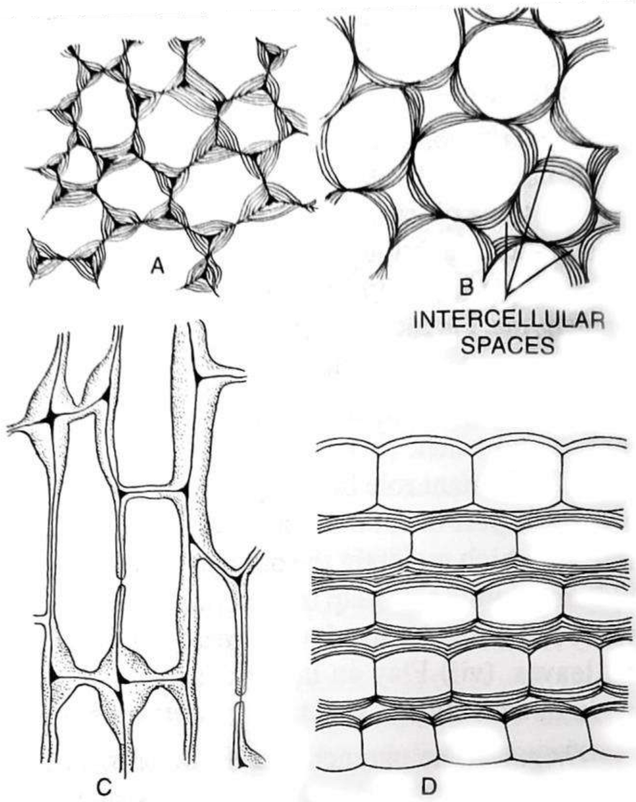


Fig.5: Different forms of collenchyma.
—Angular in t.s. C—Angular in l.s.B—Lacunate in t.s. D—Lamellar in t.s.

structurally specialised as a mechanical tissue. Collenchyma cells may or may not contain intercellular spaces.
On the basis of thickening patterns of the wall, three main types of collenchyma are recognised as follows:

(i) Angular collenchyma — Here the wall thickenings are localised at the corners or angles of the cells. Cells are compactly and irregularly arranged without any intercellular spaces.
Examples: Datura, Cucurbita, Solanum, Atropa, etc.

(ii) Lacunate or tubular collenchyma — Here, intercellular spaces are present and thickenings occur mainly on the walls around the intercellular spaces between the cells. This is also called lacumar type.
Example: Petioles of Malva, Salvia, Althea species, etc. and in the stem of Calotropis.

(iii) Plate or Lamellar collenchyma — In this type, cells are compactly arranged without intercellular spaces. Here the thickenings occur heavily in various patterns on the tangential walls rather than on the radial walls of the cells.
Example: Stems of the species of Sambucus, Rhamnus, etc.

3. Sclerenchyma: The sclerenchyma consists of thick-walled cells, often lignified, whose main function is mechanical (Fig. 6). This is a supporting tissue that withstands various strains resulting from stretching and bending of plant organs without causing any damage to the thin-walled soft cells. Sclerenchyma cells do not possess living

protoplasts at maturity. The walls of these cells are uniformly and strongly thickened. Sclerenchyma cells exhibit elastic properties.

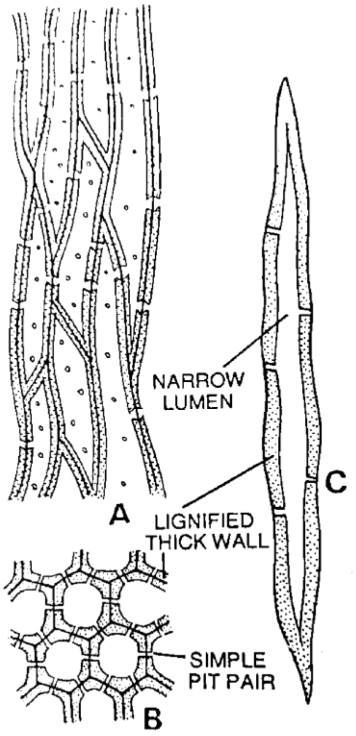


Fig.6: Sclerenchyma. A, L.S. of fibres; B, T.S. of fibre; C, a single fibre as seen in longitudinal section,

Sclerenchyma cells exhibit much variation in form, structure, origin and development. Most commonly the sclerenchyma cells are grouped into (i) fibres and (ii) sclereids.

Fibres : The fibres are elongate sclerenchyma cells, usually with pointed ends. The walls of fibres are usually lignified. Sometimes their walls are so much thickened that the lumen or cell cavity is very much reduced or altogether obliterated. The pits of the fibres are always small, rounded or slit-like and often oblique. The pits on the walls may be numerous or few in number. The middle lamella is conspicuous in the fibres. In most kinds of fibres, however, on maturation of cells the protoplast disappears and the permanent cell becomes dead and empty. Very rarely the fibres retain protoplast in them. In cross-section, fibres look angular. In some cases, like Linum sp., fibres have non-lignified walls which are made up of cellulose. Some fibres are short and some have mucilaginous cell walls.

Fibres occur in different parts of the plant body — they occur in separate strands or cylinders in the cortex and the phloem as sheath or bundle caps associated with vascular bundles, or in groups or scattered in the xylem and the phloem.

Esau (1965) classified fibres into two groups on the basis of their position in the plant body as follows:
(a) xylary fibres and (b) extraxylary fibres.

Xylary fibre

Xylary fibres develop from the same meristematic tissues as the other xylem cells and constitute an integral part of xylem. Xylary fibres are also called as intraxylary fibres or wood fibres. Xylary fibres are provided with bordered pits; these are associated with xylem. These fibres typically have lignified secondary walls. They vary in shape, size, thickness of walls and abundance of pitting. On the basis of wall thickening and types and amount of pits, xylary fibres are of two types — (a) libriform fibres and (b) fibre-tracheid.

(a) **Libriform fibres** : Libriform fibres resemble phloem fibres and are usually longer than the trachea of the plant in which they occur. These fibres are narrow with highly thickened secondary walls and reduced simple pits. Libriform fibres have a long slit-like canal, but their pit chambers are much reduced or even absent.

(b) Fibre-tracheids: These are intermediate between libriform fibres and tracheids. Their walls are of medium thickness. The pits in fibre-tracheids are bordered but their pit chambers are smaller than those of tracheids. In these, the pit-canal is elongated and the inner pit-aperture usually becomes slit-like due to the thickening of the wall. Fibre-tracheids are also regarded as reduced tracheids. Septate fibres are present in Vitis, Zingiber, etc.

Extraxylary fibres: These types of fibres occur in tissues other than the xylem. They occur in the cortex, pericycle and even in phloem. So, on the basis of their topography, extraxylary fibres may be designated as cortical fibres, perivascular fibres and phloem fibres. Usually, these fibres are long and spindle shaped, but they may vary in length and their ends may be blunt, rather than tapering or branched. The cell walls of extraxylary fibres are often very thick and some have lignified walls, while others are non-lignified. All these fibres have simple pits or slightly bordered pits. These fibres occur commonly as isolated strands or continuous bands in the cortex, in the pericycle, as caps on and around the vascular bundles and as patches in mainly monocotyledonous leaves.

Fibres give mechanical strength and rigidity to the plant body and help withstand strains and stresses. Fibres develop from different meristems such as procambium, cambium, ground meristem and also from protoderm.

Sclereids or Sclerotic cells: Sclereids are isodiametric, i.e., polyhedral in shape, and are non-parenchymatous cells, columnar, or more or less profusely branched (Fig. 7 and 8), and irregular. These are much shorter than true fibres. Sclereids are thick-walled but the thickness of the walls is not uniform. A sclereid may have a large number of simple pits. Pits are often branched. Most of the walls of sclereids are hard and lignified. Sometimes, walls may be cutinized or suberized. Sclereids are often termed as stone cells because of their hard walls. Sclereids are abundantly present in cortex, phloem, pith and mesophyll tissue as idioblasts or as cell clusters in the pericarp of fruit such as Pyrus, Psidium, etc., and in the thick testa of seeds.

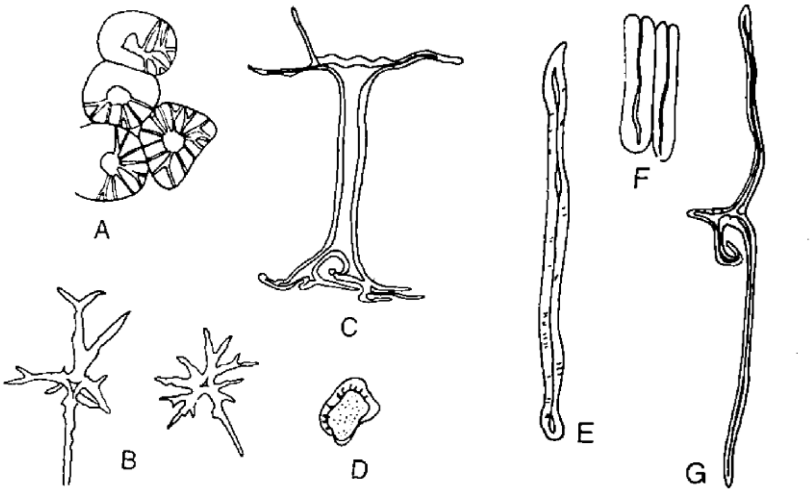


Fig.7: Different forms of sclereids. A—Brachysclereids from the pulp of *Pyrus* fruit. B—Astrosclereids from the leaf of *Trochodendron*. C—Osteosclereid from the leaf of *Hakea*. D—Brachysclereid with uneven wall thickening from the cortex of *Cinnamomum* stem. E—Macrosclereid from the pulp of apple *(Malus)*. F—Macrosclereid from the testa of *Pisum* seed. G—Trichosclereid from the leaf of *Olea*.

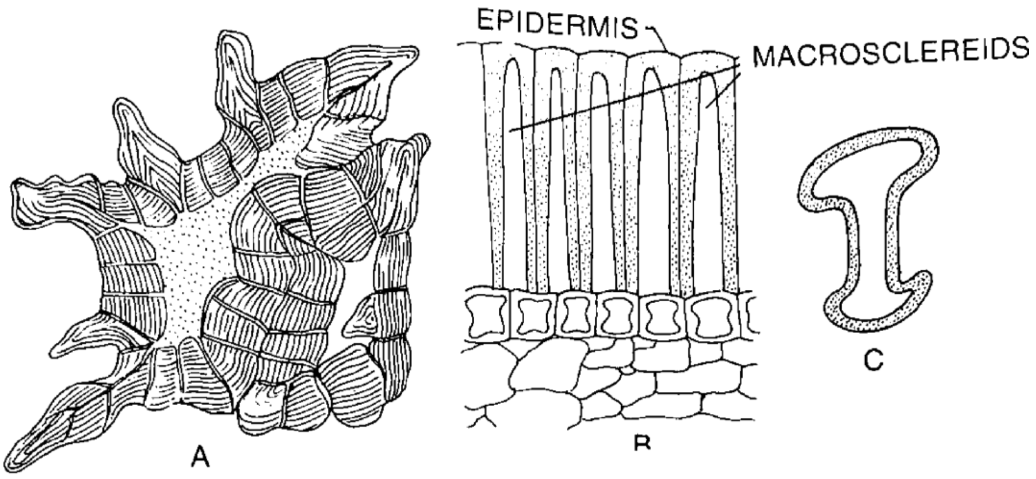
Onthe basis of shape, size and nature of the cell walls, sclereids may be of following types:

(a) Brachysclereids or stone cells: These sclereids are alike to the shape of parenchyma cells and are usually isodiametric.
Examples: Flesh of fruits of Psidium guajava, Pyrus malus, etc. and in parenchymatous tissue of cortex like Cinnamomum sp.

(b) Macrosclereids: These are elongated and rod-like cells and so columnar in shape.
Examples: Seed coat of Pisum sativum, Phaseolus mungo, etc. It may also occur in the pulp of Malus sylvestris.

(c) Osteosclereids: These are bone-shaped sclereids, columnar but enlarged at the ends.
Examples: Seed coat of Pisum and in leaves of Hakea species, etc.

(d) Astrosclereids: These are variously branched and more or less star-shaped.
Examples: In the leaves of Nymphaea, Thea, etc. Sometimes appear as idioblasts in the intercellular spaces of Nymphaea sp.



: Sclereids. A—Irregular sclereids from *Tsuga* sp. B—Macrosclereids from testa of *Phaseolus* seed. C—Osteosclereid from testa of *Pisum* seed.

(e) Trichosclereids: These are very much elongated sclereids.
Examples: In aerial roots of Monsteras p. and in leaves of Olea sp.

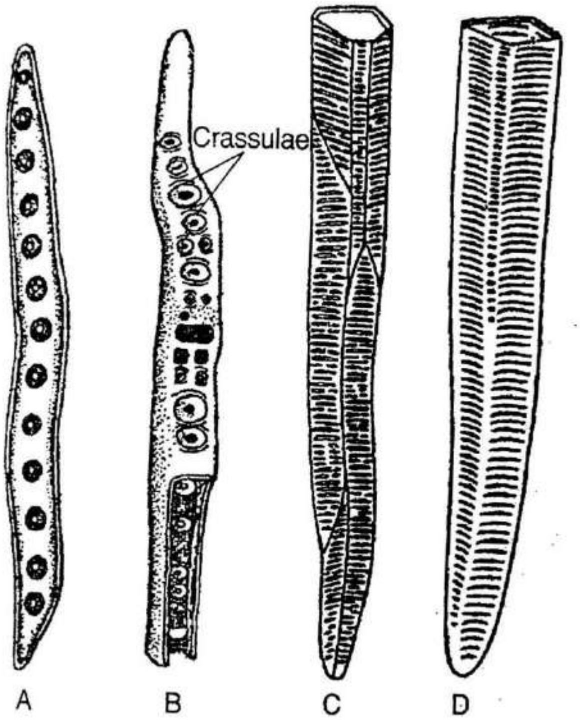
Sclereids develop from parenchyma cells and with presence of large sized nuclei. Numerous concentric layers and branched pits can be distinguished in it.

2.1.2 Complex Tissues

The vascular tissues have been treated here as complex tissues. The most important complex tissues are (i) xylem and (ii) phloem.

Xylem
Xylem is the conducting tissue which conducts water and mineral nutrients upward from the roots to the leaves. The xylem is composed of different kinds of cell elements. These are tracheids, fibres and fibre-tracheids, vessels or tracheae, wood fibres and xylem or wood parenchyma. The xylem is also meant for mechanical support to the plant body. Moreover, it is concerned with water conduction and storage.

Tracheids
Tracheid is the fundamental cell type in xylem. It is an elongated tube-like cell having tapering, rounded or oval ends with hard and lignified walls.



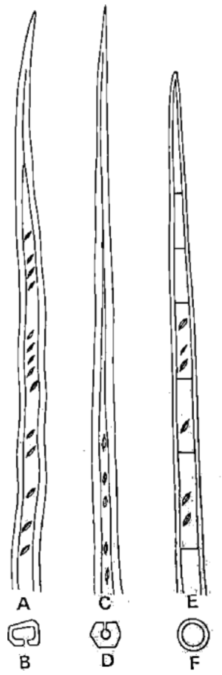
Tracheids : A. Bordered pitted tracheid.
B. Bordered pits with crassulae on a portion of a tracheid.
C & D. Parts of tracheids with scalariform thickening

without protoplast and dead on maturity. In transverse section the tracheid look angular though more or less rounded form also occur. The walls of tracheids have various types of bordered pits. Tracheids also have various types of thickening such as annular, spiral, scalariform, reticulate, pitted, etc. The tracheids are especially adopted to the function of conduction. Due to their firm and rigid walls they also give mechanical support for the plant body.

Fibres and fibre-tracheids

Fibres and fibre-tracheids are developed from tracheids due to decrease in the length of tracheids and due to narrowness in the lumen (Fig. 10). In these cells either very little conduction of water or no conduction of water takes place. These are known as fibres. Between such cells, or between fibres and normal tracheids, there are many transitional forms which may be either termed as typical fibres or typical tracheids. These **transitional types may be termed as fibre-tracheids. The pits of fibre-tracheids are smaller than those of vessels and typical tracheids. However, a line of demarcation cannot be drawn in between tracheids and fibre-tracheids and between fibre-tracheids and fibres. When fibres possess very thick walls and reduced simple pits, they are known as libriform wood fibres because of their similarity to phloem fibres. The libriform wood fibres mainly occur in woody dicotyledons, for example, in the members of Leguminosae. The walls of fibre-tracheids and fibres of many genera of different families possess gelatinous layers. The cells possessing such layers are known as gelatinous tracheids, fibre-tracheids and fibres. In certain fibre-tracheids the protoplast persists after the secondary wall is matured and may divide to produce two or more protoplasts. These protoplasts are separated by a thin**

transverse partition wall. Such fibre-tracheids are termed as septate fibre-tracheids. Here, the transverse partitions are true walls and each chamber has a protoplast with a nucleus.



Wood fibres and fibre-tracheids. A and B, L.S. and T.S. of fibre-tracheid from *Malus pumila*; C and D, L.S. and T.S. of libriform fibre from *Quercus alba*; E and F, L.S. and T.S. of septate fibre-tracheid from *Swietenia*

Vessles

These are long tube arranged in vertical rows formed of cylindrical cells arranged end to end with their end walls completely or partially dissolved. Tracheid develop into vessels by the enlargement and pore formation. In the more primitive types of vessels,the general form of tracheid is retained and increase in diameter is not much. In the most advanced types, increase in diameter is much and the cell becomes drum-shaped as in Quercus alba. The tracheid is sufficiently longer than the cambium cell. The most advanced type of vessel retains the length of the cambium cell or is somewhat shorter, with a diameter greater than its length (drum-shaped vessel). The ends of the cell change in shape in the series from least to high specialization. The angle formed by tapering end wall becomes greater until the end wall is at right angle to the side walls. Usually the diameter of vessels is much greater than that of tracheids and due to the presence of perforations in the partition walls they form long tubes through whic**h water is being conducted from** root to leaf. The pits are often more numerous and smaller in size than are those of tracheids and cover the wall closely. The openings in vessel element walls are known as perforations; these openings are restricted to the end walls except in certain slender, tapering types. Where there is the presence of perforation that is known as perforation plate. The perforation plate, when it bears a single opening, is described as having simple perforation. If there are two or more openings, they are known as multiple perforations. On the mode of thickening of secondary wall, vessels are known as annular, spiral, scalariform or pitted. Vessels are characteristic of the angiosperms. However, certain angiospermic families like Winteraceae, Trochodendraceae and Tetracentraceae, and in many monocotyledons except Yucca and Dracaena, lack vessel elements.

Wood fibres

Wood fibres consist of long, narrow, thick-walled, lignified cells. Fibres remain associated in xylem with other elements. Two major types of xylem fibres are recognised, e.g., fibre-tracheids and the libriform fibres. These two types of fibres generally remain intermingled with each other. Fibre-tracheids have bordered pits with cavities smaller than the pit cavities of tracheids or tracheae. Libriform fibres are narrow with thick secondary walls with pits, and the pit is simple and has a slit-like aperture towards the cell lumen.

Xylem parenchyma or wood parenchyma: In most plants, one of the important constituents of the xylem is the living parenchyma cells. In secondary xylem such cells occur vertically, more or less elongated and placed end to end, and these parenchyma cells are known as xylem or wood parenchyma. The radial transverse series of the cells form the wood rays and are known as xylem or wood ray parenchyma. The ray and the xylem parenchyma cells of the secondary xylem may or may not have secondary walls. If a secondary wall is present, the pit pairs between the parenchyma cells and the tracheary elements may be simple, half bordered and bordered. In between parenchyma cells only simple pit pairs occur. The xylem parenchyma cells are noted for storage of food in the form of starch or fat. Tannins, crystals and various other substances also occur in xylem parenchyma cells. These cells assist directly or indirectly in the conduction of water upward through the vessels and tracheids.

Phloem

This complex tissue is a constituent of the vascular tissues of plants. The xylem and phloem have evolved along more or less similar lines. In phloem, the basic cell type is the sieve element. There are two forms of sieve element—the primitive form is the sieve cell of gymnosperms and lower forms where series of united cells do not exist, the unit of a series, the sieve tube element. Phloem is the main organic food-conducting tissue of vascular plants. Phloem consists of the following elements:
(a) sieve elements, (b) companion cells, (c) phloem fibres and (d) phloem parenchyma (Fig. 11).
In the pteridophytes and gymnosperms, only sieve cells and phloem parenchyma are present. In some gymnosperms, sieve cells, phloem parenchyma and phloem fibres are present. In angiosperms, sieve tubes, companion cells, phloem parenchyma, phloem fibres, sclereids and secretory cells are present.

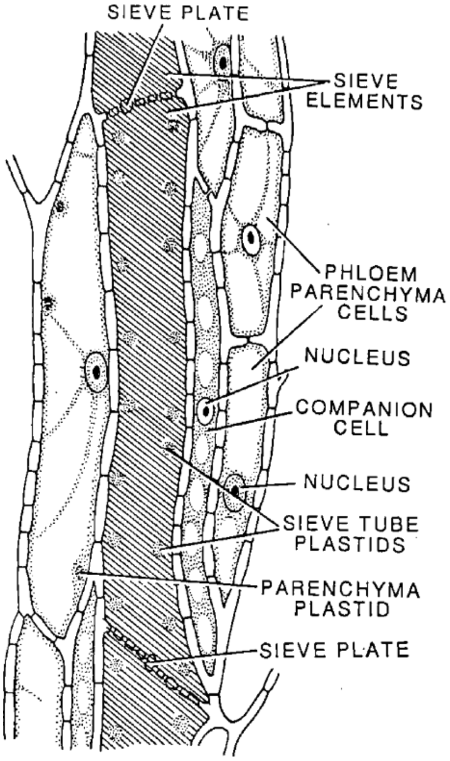


Fig. 11: Phloem tissue from the stem of *Nicotiana*.

Sieve elements

The conducting elements of the phloem are collectively known as sieve elements. They may be segregated into the less specialized sieve cells and more specialized sieve tubes or sieve tube elements. The morphological specialization of sieve elements is expressed in the development of sieve areas on their walls and in the peculiar modifications of their protoplasts. The sieve areas are depressed wall areas with clusters of perforations through which the protoplasts of the adjacent sieve elements are interconnected by connecting strands. In a sieve area, each connecting strand remains encased in a cylinder of substances called callose.

The wall parts bearing the highly specialized sieve areas are called sieve plates. The sieve plate consists of a single sieve area; it is a simple sieve plate. Many sieve areas, arranged in scalariform, reticulate, and in any other manner, constitute a compound sieve plate. Sometimes sieve tube elements may have a sieve plate in their lateral walls.

Sieve cells and the sieve tube elements differ in the degree of differentiation of their sieve areas and in the distribution of these areas on the walls. Sieve cells are commonly long and slender, and they are tapering at their ends. In the tissue, they overlap each other and the sieve areas are usually numerous on these ends. In sieve tube elements, the sieve areas are more highly specialized than others and are localized in the form of sieve plates. The sieve plates occur mainly on end walls. Sieve tube elements are usually disposed end to end in long series, the common wall parts bearing the sieve plates. These series of sieve elements are sieve-tubes.

The sieve elements generally possess primary walls, mainly of cellulose. The characteristic of the primary walls of sieve elements is their relative thickness. The most important characteristic feature of the sieve element protoplast is that it lacks a nucleus when the cell completes its development and becomes functional. The loss of the nucleus occurs during the differentiation of the element. In the meristematic state, the sieve element resembles other procambial or cambial cells in having a more or less vacuolated protoplast with a conspicuous nucleus. Later, the nucleus disorganizes and disappears.

An important property of the sieve element protoplast of dicotyledons is the presence of a variable amount of a relatively viscous substance, the slime. It is proteinaceous in nature. The slime appears to be located mainly in the cell sap together with various organic and inorganic ingredients. The slime originates in the cytoplasm in the form of slime bodies.

Companion cells

The companion cell is a specialized type of parenchyma cell which is closely associated in origin, position, and function with sieve tube elements. When seen in transverse section, the companion cell is usually a small, triangular, rounded, or rectangular cell beside a sieve tube element. These cells are living, having abundant granular cytoplasm and a prominent elongated nucleus which is retained throughout the life of the cell. Usually, the nucleus of the companion cells serves for the sieve tubes as they lack them. They live only so long as the sieve tube element with which they are associated, and they are crushed with those cells. Companion cells are formed by longitudinal division of the mother cell of the sieve tube element before specialization of this cell begins. One daughter cell becomes a companion cell and the other is a sieve tube element. The companion cell initial may divide transversely several times, producing a row of companion cells so that one to several companion cells may accompany each sieve tube element. A companion cell or a row of companion cells formed by the transverse division of a single companion cell initial may extend the full length of the sieve tube element. The solitary and long companion cells occur in primary phloem of herbaceous plants, and numerous companion cells occur in the secondary phloem of woody plants. The number of companion cells accompanying the sieve tube is constant for a particular species. These cells help the sieve tube in the conduction of food. The companion cells occur only in angiosperms, where they accompany most sieve-tube elements. The sieve cells of the gymnosperms and vascular cryptogams have no companion cells.

Phloem fibres

Phloem fibres or bast fibres occur in primary and secondary phloem. Only simple pits are found on the walls of phloem fibres. The walls of phloem fibres may be lignified as in Cannabis sp. (hemp) or non-lignified as in Linum sp. (flax); here, the walls are cellulosic. Due to the strength of strands of phloem fibres, they have been used for a long time in the manufacture of cords, rope, mats, and cloth. Phloem fibres are also known as bast or bass fibres. The sclereids are seldom found in the primary phloem. The older secondary phloem of many trees also contains the sclereids.

Phloem parenchyma

Phloem parenchyma consists of some parenchymatous cells which may be elongated, pointed, cylindrical, or sub-spherical in shape. These are concerned with many activities characteristic of living parenchyma cells, such as storage of starch, fat, and other organic substances. Tannins and resins are also found in these cells. There are two systems of parenchyma found in the secondary phloem. These systems are vertical and horizontal. The parenchyma of the vertical system is known as phloem parenchyma. The horizontal parenchyma is composed of phloem rays. In the active phloem, the phloem parenchyma and the ray cells have only primary unlignified walls. The walls of both kinds of parenchyma cells have numerous pit fields. The phloem parenchyma is not found in many or most of monocotyledons.

The conducting elements of the phloem

The conducting elements of the phloem are collectively known as sieve elements. They may be segregated into the less specialized sieve cells and the more specialized sieve tube or sieve tube elements. The morphological specialization of sieve elements is expressed in the development of sieve areas on their walls and in the peculiar modifications of their protoplasts. The sieve areas are depressed wall areas with clusters of perforations through which the protoplasts of the adjacent sieve elements are interconnected by connecting strands. In a sieve area, each connecting strand remains encased in a cylinder of substances called callose.

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An important property of the sieve element protoplast of dicotyledons is the presence of a variable amount of a relatively viscous substance, the slime. It is proteinaceous in nature. The slime appears to be located mainly in the cell sap together with various organic and inorganic ingredients. The slime originates in the cytoplasm in the form of slime bodies.

Summary

From the discussion it can be concluded that the knowledge of permanent tissues as well as the simple and complex tissues have been achieved in different group of plants. Group of names of the cells that are alike in origin, structure, and function form tissues. The plant body consists of vegetative tisses and reproductive tissue.In the higher group of plants, the plant body is some what more complex in its cellular structure. The cells differ very much in their kind, form and origin in higher plants.Detail knowledge of simpleandcomplex permanent tissues can easily be understand specially structure and function of both the simple tissues like parenchyma, collenchyma and sclerenchyma and complex tissue like Xylem and Phloem.

Questions

4. Define tissue. Describe different types of permanent tissues in plants.
5. Define fibre tracheids. Compare fibres and fibre tracheids.Write notes on wood fibres.
6. Describe in brief about the phloem elements.

Answers

4. See articleno.2.1
5. See articleno.2.2
6. See articleno.2.3

Unit 3: Primary Structure

3.0 Objective

Study of root structure of both dicotyledonous and monocotyledonous plants gives a better idea related to the disposition of various layer within the root system. Wide cortex and small pith present in dicotyledonous root whereas wide cortex and large pith in monocotyledonous root.

Study of the characteristic structural detail of anatomical features of both dicotyledonous and monocotyledonous stems, bear much importance. Arrangement of vascular bundles in both the cases can be identified as in dicotyledons it is in ring like manner but in monocotyledons bundles are lying scattered with in the ground tissue.

From the dicotyledonous leaf anatomy designation of leaf surface that is continous with the surface of the part of the stem located above the leaf insertion can easily be traced. On the other hand in monocotyledonous leaves the internal structure reveals the nature of mesophyll tissue in it.

3.1 Introduction

Root constitutes the underground part of the plant axis specialized as an absorbing and anchoring organ which develops from the radicle of embryo.

The vascular bundles in roots are radial, xylem is exarch. The number of boundles varies from two to six in dicotyledonous root and are numerous ie., polyarch in monocotyledonous root.

The vegetative body of the sporophyte of the vascular plant is customarily divided into three so-called organs as stem, leaf and root. The stem is the aerial and ascending part of the axis of a plant that bears the leaves and reproductive structures.

Generally the leaves are of two types ie., dorsiventral leaves and isobilateral leaves. The dorsiventral leaves usually grow in horizontal direction with distinct upper and lower surface to receive direct and equal amount of sun light.

The arrangement of vascular bundles as well as vascular tissues in stems, roots and in leaves are the important features of identity of the organs of plants. The vascular bundles are conjoint, collateral, open or clased in stems while these bundles are radial in roots. Moreover, the arrangement of xylem within vascular bundles, whether endarch, exarch or mesarch, is a very important feature of identity (Fig. 12, 13). There may be the presence of bicollateral vascular bundles as found in members of the family Cucurbitaceae (Fig. 13).

Primary structure of atypical dicotyledonous root

Transverse section of atypical dicotyledonous root in early stages, on examination under microscope, shows a well defined epidermis on the outside, a wide cortex and a small stele at the centre. A pith may or may not be present in the stele.

Epidermis : The epidermis consists of closely packed elongated cells with thin walls that usually lack cuticle and stomata. In some dicotyledons, thickened outer walls occur in root parts growing in air and also in roots that retain their epidermis for a long time. The root epidermis is also known as the piliferous layer, rhizodermis or epiblema. Epidermis is typically uniseriate. Most of the epidermal cells extend out in the form of tubular unicellular root hairs.

Cortex : The cortex is massive and consists of thin-walled rounded or polygonal parenchyma cells having sufficiently developed intercellular spaces. The parenchyma cells of the cortex contain abundant starch grains within them. In the roots of dicotyledons which possess secondary growth and shed their cortex early, the cortex consists mainly of parenchyma. In aquatic plants the intercellular spaces are large and form distinct air spaces. The cortex of roots is usually devoid of chlorophyll. Exceptions are in the roots of some aquatic plants and aerial roots of many epiphytes like Tinosporas pp. Various idioblasts and secretory structures are found in the cortex root of some dicotyledons like Brassica, Pyrus, Prunus, Spiraea where in many roots develop prominent reticulate or band-like thickenings in the cortical cells outside the endodermis.

Endodermis : The innermost distinct layer of the cortex is known as endodermis. The endodermis is uniseriate and almost universally present in the roots. The cells of endodermis are living and are characterized by the presence of abundant starch grains within them. It is made up of elongated cells, which appear barrel-shaped in cross section. The cells are thin-walled but the radial walls are thickened. These strips of thickening on the radial walls are known as Casparian bands. The cytoplasm of an endodermal cell remains firmly attached to the Casparian strip. This firm attachment controls the movement of the materials in the root and their passage into xylem cells.

Pericycle : The layer next to the endodermis is commonly known as pericycle. The pericycle is made up of a single layer of parenchymatous cells. It makes the outer boundary of the primary vascular cylinder of the dicotyledonous roots. Roots without pericycle are rare but may be found among aquatic plants and parasites.

Vascular system : The phloem of root occurs in the form of strands distributed near the periphery of the vascular cylinder, beneath the pericycle. Generally, the xylem forms discrete strands, alternating with the phloem strands. Sometimes the xylem occupies the centre, with the strand-like parts projecting from the central core like ridges. If xylem is not differentiated at the centre, the centre is occupied by a pith. The root typically shows an exarch xylem, i.e., the protoxylem is located near the periphery of the vascular cylinder and the metaxylem towards the centre (Fig. 12, 13). The phloem is also centripetally differentiated, i.e., protophloem occurring closer to the periphery than the metaphloem. Most dicotyledonous plants have few xylem strands. The tap root is frequently di-tri-tetrarch. The phloem strand consists of sieve tubes, companion cells and phloem parenchyma. The parenchymatous conjunctive tissue occurs in between xylem and phloem strands. The pith is scanty or altogether absent.

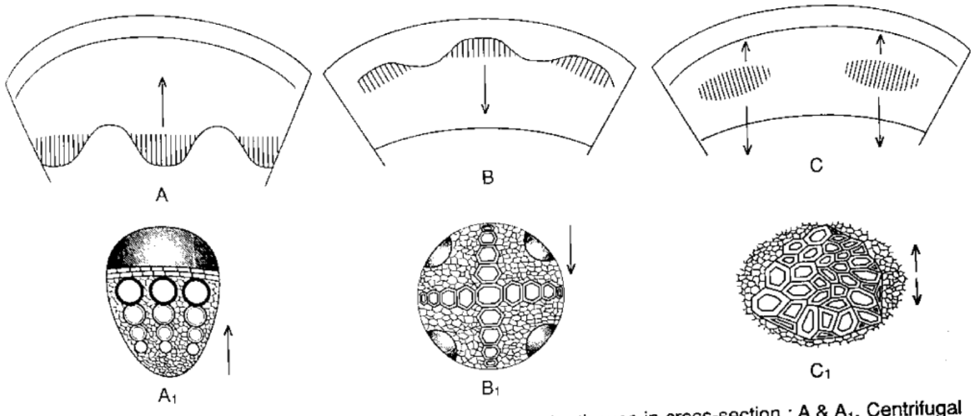


Fig.12: Diagrams showing order of development of primary vascular tissues in cross-section : A & A_1. Centrifugal development with endarch xylem. B & B_1. Centripetal development with exarch xylem. C & C_1. Both centripetal and centrifugal development with mesarch xylem

Primary structure of atypical monocotyledonous root

Typical anatomical structure of monocotyledonous roots are as follows:

Epidermis : The epidermis or outermost layer of the root is commonly known as rhizodermis, epiblema or piliferous layer. It is uniseriate and composed of compact tubular cells having no intercellular spaces and stomata. The tubular unicellular root hairs are also present on this layer. A well known example of a multiseriate epidermis is the velamen of aerial roots of orchid and epiphytes. The velamen is a parenchyma-like sheath consisting of compactly arranged nonliving cells with thickened walls. Cells of velamen are quite big in size and contain air and water in them. The cell walls develop fibrous thickenings. Generally, beneath the epidermis there are one or more layers of exodermis. Usually, the exodermis consists of a single row of cells with thickened outer and lateral walls except certain passage cells which remain thin-walled.

Cortex : Immediately beneath the epidermis, a passive cortex lies consisting of thin-walled parenchyma cells having intercellular spaces among them. Usually, in an old root of Zea mays, a few layers of cortex immediately beneath the epidermis undergo suberization and give rise to a simple or multilayered zone — the exodermis. This is a protective layer which protects internal tissues from injury. The starch grains are abundantly present in the cortical cells. The sclerenchyma cells are commonly found in the cortex of monocotyledons.

Endodermis : The innermost layer of the cortex is called the endodermis. It is composed of barrel-shaped, compact cells having no intercellular spaces among them. The endodermal cells possess Casparian strips on their anticlinal walls. The Casparian strip is part of the primary cell wall. It is typically located close to the inner tangential wall. The walls of endodermal cells are sufficiently thick, and therefore, the thin-walled passage cells are formed opposite to the protoxylem poles. These passage cells are meant for diffusion and are also called the transfusion cells.

Pericycle : It is usually uniseriate and composed of thin-walled parenchymatous cells. In monocotyledons, the pericycle often undergoes sclerification in older roots, partly or entirely. The pericycle in monocotyledons consists of several layers as in the members of Gramineae, Smilax, Agave, Dracaena, and Palms, etc.

Vascular tissue : The vascular tissue consists of alternating strands of xylem and phloem. The phloem occurs beneath the pericycle in the form of strands near the periphery of the vascular cylinder. The xylem forms discrete strands alternating with the phloem strands. The centre is occupied by a large pith which may be parenchymatous or sclerenchymatous. Bundles are numerous and are referred to as polyarch.
The xylem is exarch, i.e., the protoxylem lies towards the periphery and the metaxylem towards the centre. The vessels of protoxylem are narrow and the walls have annular and spiral thickenings, whereas in metaxylem the vessels are broad and possess reticulate and pitted thickenings.
The phloem strands consist of sieve tubes, companion cells, and phloem parenchyma. The phloem strands are also exarch, having protophloem towards the periphery and metaphloem towards the centre. The parenchymatous or sclerenchymatous conjunctive tissue is found in between and around the xylem and phloem strands. The central part of the stele is occupied by a well-developed pith. The pith is sclerenchymatous in Canna, Oryza sativa, Avena sativa.

Primary structure of atypical dicotyledonous stem

Transverse section of young stem shows three well-defined zones or tissue systems such as the epidermal zone, cortical zone, and vascular zone.

Epidermis : This forms the outermost layer and consists of cells flattened tangentially and fitting closely along their radial walls with a well-defined cuticle extending over it. Here and there it bears some multicellular hairs and a few stomata, but no chloroplasts. The guard cells of the stomata, however, contain chloroplasts. The epidermis serves mainly to restrict the rate of transpiration and to protect the underlying tissues from mechanical injury and from disease-producing organisms.

Cortex : The region that lies next to the epidermis is the cortex. The innermost layer of the cortex is the endodermis, known as the starch sheath. It consists of a single layer of cells which surrounds the stele and contains numerous starch grains. Frequently it is most easily distinguishable from the surrounding tissue by the presence of these starch grains. The part of the cortex situated between the epidermis and the endodermis is generally divided into two regions: an outer zone of collenchyma cells and an inner zone of parenchyma cells.

Collenchyma : On the inner side of the epidermis, there is usually a band of collenchyma. The cells of the collenchyma are modified parenchyma cells with cellulose walls thickened at the angles where three or more cells are in contact. The collenchyma resembles parenchyma in being alive and having a moderate amount of protoplasm. The main function of collenchyma cells is to serve as strengthening material in succulent organs which do not develop much woody tissue. Sometimes, collenchyma cells in stems that contain chloroplasts carry out photosynthesis.

Parenchyma : The parenchyma cells are generally regular in shape, have comparatively thin walls, and are not greatly elongated in any direction. They are living cells and contain a moderate amount of protoplasm. When exposed to light, these cells often develop chloroplasts and are known as chlorenchyma. These chlorenchyma cells perform photosynthesis. Parenchyma cells play an important role in succulent stems and in young parts of the stems of woody plants before strong mechanical tissues have been developed. The parenchyma cells serve for the slow conduction of water and food. The parenchyma also acts as a special storage tissue of plants.

Sclerenchyma: The sclerenchyma cells are found in the cortex of some stems. It may be of two types — short or irregularly shaped cells, known as stone cells and sclerenchyma fibres. Sclerenchyma fibres are long, thick-walled dead cells and serve as strengthening material. On the other hand, stone cells give stiffness to the cortex.

Endodermis: The innermost layer of the cortex is the endodermis consisting of barrel-shaped, elongated, compact cells without intercellular spaces. As endodermal cells contain starch grains, so it may be termed as starch sheath.

Stele: The zone inside the cortex is known as the stele. Stele is constituted with three regions, i.e., the pericycle, the vascular bundle and the pith.

Pericycle: This is the region lying in between the endodermis and vascular bundle and is represented by semi-lunar patches of sclerenchyma and the interveining masses of parenchyma. This type of pericycle is known as heterogenous pericycle.

Vascular bundles: These are collateral, open and are arranged in a ring. Each bundle is composed of phloem, xylem and cambium (Fig. 13).

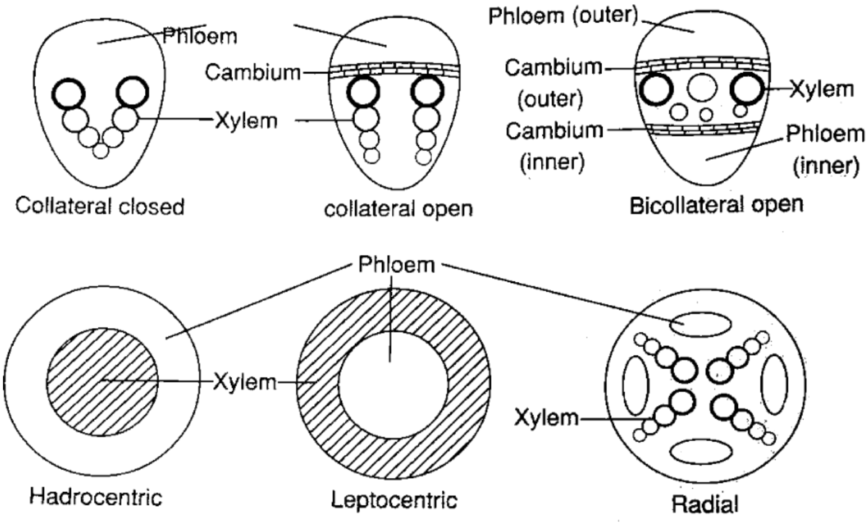


Fig.13: Diagrammatic drawing showing different types of vascular bundles

(a) Phloem: This lies externally and is composed only of this cellulose-walled elements. It consists of sieve tubes, companion cells and phloem parenchyma.

The sieve tubes consist of thin-walled, elongated cells arranged in vertical rows. The adjacent cells of sieve tubes which contain such holes are termed as sieve plates. Mature sieve tubes do not have any nuclei. The sieve tubes primarily serve for the conduction of food material. The companion cells are small cells which are attached to the sieve tubes. Each companion cell is the sister cell of a sieve tube cell, the two being formed by the division of a mother cell. The rest of phloem is packed with small-celled parenchyma known as phloem parenchyma. They contain food materials.

(b) Xylem: The xylem which is formed before the activity of cambium has begun to produce xylem is called primary xylem. The xylem formed first is nearest the centre of the stem and is called protoxylem. The peripheral part of the primary xylem is known as metaxylem.
The xylem is composed of three different types of cells—tracheary cells, that include tracheids and vessels; wood fibres and wood parenchyma.
The tracheids are elongated dead cells, with walls that are thick in some places and thin in others. They serve both as water-conducting and as strengthening cells. The walls of tracheids are heavily impregnated with lignin.
The vessels are composed of rows of tracheary cells and the cavities of which are connected by the total or partial disappearance of the cross walls. The diameter of vessels is much greater than that of tracheids. They form long tubes and therefore, they constitute the principal water-conducting elements of dicotyledonous stem.
The protoxylem is composed of annular and spiral vessels and parenchyma, while the tracheary elements of the secondary xylem are pitted.
The wood fibres are long, slender, pointed dead cells with greatly thickened walls and only comparatively few small pits. They act as strengthening cells. The tracheids which have a structure like that of wood are termed as fibre-tracheids.
The xylem, along with parenchyma, is known as wood parenchyma. They serve mainly for the storage of food.

(c) Cambium: Just below the phloem, a band of thin-walled tissue is seen called cambium, whose cells are regularly arranged in radial rows and are roughly rectangular in shape, very small in size. Cambium by division gives rise to xylem towards the centre of the stele and phloem towards the periphery. Initially the cambium is confined to the bundles, but later the parenchyma cells of the pith rays which lie between the edges of the cambium in vascular bundles divide and form a layer of cambium which reaches across the pith rays and connects that in the bundles, so that the cambium becomes a continuous cylinder.

Pith rays: The vascular bundles are separated from each other by radial rows of parenchyma cells known as pith rays. The pith ray cells are usually elongated in a radial direction. They serve primarily for the conduction of food and water radially in the stele and for the storage of food.

Pith: In dicotyledonous plants, the centre of the stele is composed of thin-walled parenchyma cells and that is known as pith.

Typical primary anatomical structure of monocotyledonous stem

The monocotyledonous stems are similar to dicotyledonous stems in having an epidermis, a cortex and a stele. The cortex may be well developed and sharply marked off from the stele, or it may be quite narrow and inconspicuous. The structure and arrangement of vascular bundles of monocotyledonous stems differ from dicotyledonous stems (Fig. 14).

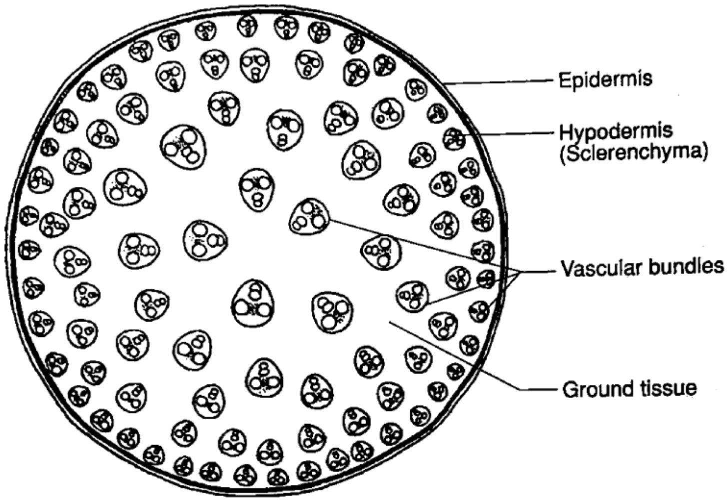


Fig.14: Diagrammatic view of the transverse section of a young maize stem

Typical structural composition or arrangement areas are as follows:

Epidermis : The epidermis consists of a single layer of compact cells, without any intercellular spaces. Epidermal cells are mostly tubular—polygonal in case of Canna scape and mostly rounded in case of Asparagus. It is covered with a thick cuticle. The epidermal hairs are altogether absent. Stomata are present in Triticum aestivum stem.

Hypodermis : Below the epidermis, usually two or three layers of sclerenchyma hypodermis are present in case of Zea mays stems.

Ground tissue : It consists of thin-walled parenchyma cells, well-defined intercellular spaces among them. The tissue extends from below the sclerenchyma (hypodermis) to the centre in case of Zea mays. In case of Asparagus, just beneath the epidermis a few layers of chloroplast-containing parenchyma are found. These may be termed as cortex. The innermost layer of the cortex consists of compact cells and is termed as starch sheath. Below the starch sheath, a multilayered complete band of sclerenchyma occurs, which gives mechanical rigidity to the stem. The rest of the portion is ground tissue which consists of thin-walled parenchyma cells having well developed intercellular spaces among them.

In case of Canna stem, just beneath the epidermis a few layers of parenchyma occur forming a small cortical region. Cortical cells are polygonal and large. Immediately below the cortex, a single layer of chlorophyllous tissue is found consisting of chloroplast-bearing cells. The sclerenchyma patches remain attached to the chlorophyllous tissue here and there. Next to this, a continuous mass of large, thin-walled, parenchymatous cells having sufficiently developed intercellular spaces are present. It is the ground tissue.

In case of Triticum aestivum, just beneath the epidermis sclerenchyma cells occur in small patches and are interrupted by chlorenchyma tissue here and there. The rest of the ground tissue consists of thin-walled, rounded or oval parenchyma cells having prominent intercellular spaces. The central part of the stem is hollow.

Vascular bundles : It is composed of many collateral and closed vascular bundles scattered in the ground tissue. The vascular bundles in the periphery are greater in number than the centre and peripheral bundles are smaller in size than the central ones. Each bundle is more or less surrounded by a sclerenchyma bundle sheath. The bundle consists of xylem and phloem.

Usually the xylem is ‘Y’-shaped and consists of pitted and bigger vessels of metaxylem and smaller vessels (annular, spiral) of protoxylem. In between metaxylem vessels, small pitted tracheids are also found. The lysigenous cavity is formed by the breaking down of the inner protoplasm of the vessel.

The phloem consists of sieve tubes and companion cells. Phloem parenchyma is altogether absent in most monocotyledonous stems. Sieve tubes and companion cells are quite conspicuous.

Anatomical structure of atypical dicotyledonous leaf

The dicotyledonous leaf is usually bifacial and dorsiventral. It is made up of parenchymatous mesophyll tissue with the epidermis on the upper and lower side (Fig. 15a). The epidermis is made up of closely packed, rectangular and flattened cells.

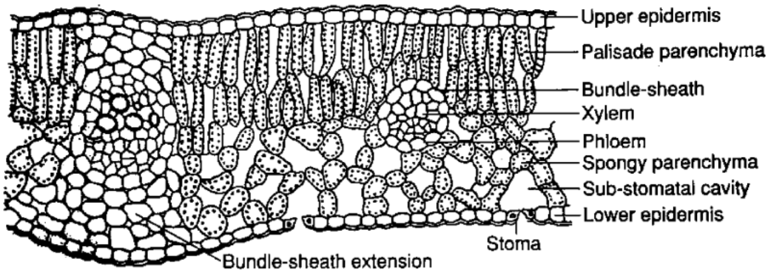
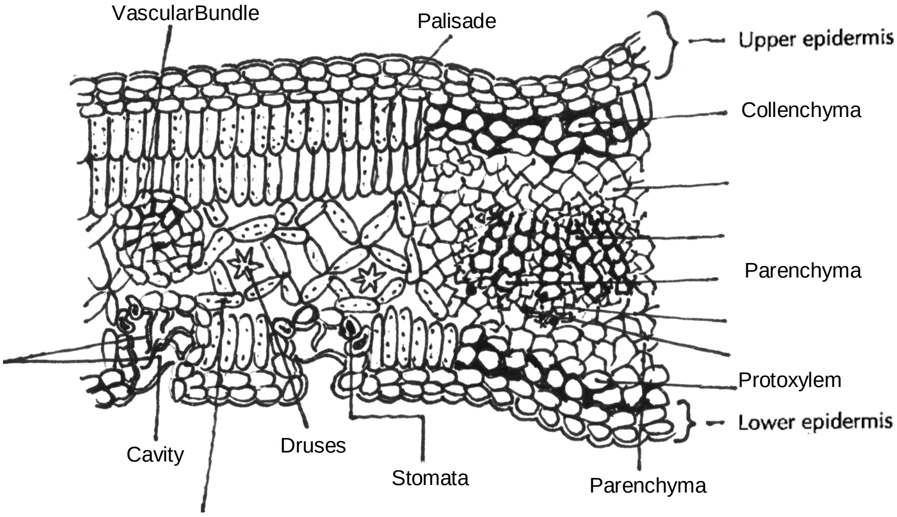


Fig.15a: Transverse section of a portion of a mango leaf



with thin walls. Cells are vertically elongated. Epidermis is usually unilayered but in many leaves like Nerium and Ficus it is multilayered. In leaves of shady places the cell wall of epidermis is thin but in xerophytes it is thickened (15b). Some leaves like waterlily possess a layer of wax on the upper epidermis which prevents wilting of the leaf. Usually, the upper surface lacks stomata, but the lower surface of leaf contains stomata. The number of stomata in the lower epidermis of a dorsiventral leaf is higher. They are very few in the upper epidermis and sometimes altogether absent. In the floating leaves, stomata remain confined to the upper epidermis while in the submerged leaves the stomata are absent. In xerophytic plants in the leaves, stomata are either sunken or situated inside depressions.

Usually, the stomata are meant for the exchange of gases between the plant and the atmosphere. Transpiration takes place through the stomata and the surplus water is evaporated.

The mesophyll is made up of two types of cells, the palisade tissue below the upper epidermis and the spongy tissue on the lower side.

The vein containing the vascular tissue is disposed between the palisade and spongy cells. The cells of palisade tissue are narrow and elongated at right angles to the epidermis. They are parenchymatous in nature with thin walls.

The palisade tissue may be one-layered as in Lawsonia or two-layered as in Helianthus and Ficus. These cells contain a large number of chloroplasts. They are photosynthetic in nature. The spongy tissue is made up of many layers of cells. A lower concentration of chloroplasts is present in these cells. The intercellular spaces in spongy cells are conspicuous. These cells are also concerned with photosynthesis.

Vascular tissue is located in the veins. There is usually one main vein called the midrib; the secondary veins and the veinlets form a network over the mesophyll cells. These are more or less oval cells with cuticularised outer walls.

Sometimes the leaves hang vertically (e.g., Eucalyptus), so that both surfaces of the leaf are equally illuminated. In such leaves the palisade parenchyma may occur on both sides. The leaves which receive direct sunlight develop more compact parenchyma in comparison to the leaves which develop in shady places.

Due to the presence of large air spaces in the spongy tissue, they are more adaptable to the exchange of gases between the cells and the atmosphere.

Both spongy and palisade parenchyma contain discoid chloroplasts arranged in parallel rows in the cells. As the chloroplasts are denser in the palisade tissue than in the spongy tissue, the upper surface of the leaf appears to be a deeper green than the lower surface.

The tissues which constitute the conducting system are situated near the centre of the midrib. This system may have various shapes, e.g., the form of a ring, a crescent-shaped ring, a crescent arc, or scattered patches. In the ring-shaped conducting system, parenchyma cells are usually found in the centre of the ring. The inner part of the ring is composed of xylem towards the upper surface and phloem towards the lower surface.

Xylem is composed of various kinds of vessels, tracheids, wood fibres, and wood parenchyma. Specifically, the vessels are annular and spiral. Xylem conducts water, raw food materials and also gives mechanical support to the leaf. The phloem consists of sieve tubes, companion cells, and phloem parenchyma. The phloem serves for the translocation of prepared food material from the mesophyll of the leaf. Here xylem is of the mesarch type. The large vascular bundles of dicotyledonous leaves are closed, collateral, and remain surrounded by parenchyma with small numbers of chloroplasts. In dicotyledons, the bundle sheath parenchyma is also called border parenchyma. In certain dicotyledonous leaf bundles, the sheath is enclosed by sclerenchyma (members of Winteraceae, Melastomaceae, etc.).

Anatomical structure of a typical monocotyledonous leaf

The monocotyledons as a group show greater diversity of specialized leaf type. In general, monocotyledonous leaves are parallel-veined. Most monocotyledonous leaves are nearly erect and both surfaces usually receive direct and equal amounts of sunlight. Such leaves are called isobilateral. The internal structure of such leaves is more or less similar in both the upper and lower halves. The epidermis on either side contains the stomata and the mesophyll is usually not differentiated into palisade and spongy parenchyma but consists only of parenchyma cells, having chloroplasts and intercellular spaces among them (Fig. 16 & 17).

Internal structure of Zea mays (Fig. 18) leaf is as follows:

Epidermis : The epidermis is found on both the upper and lower surfaces of the leaf. The epidermal layers are uniseriate and composed of more or less oval cells.

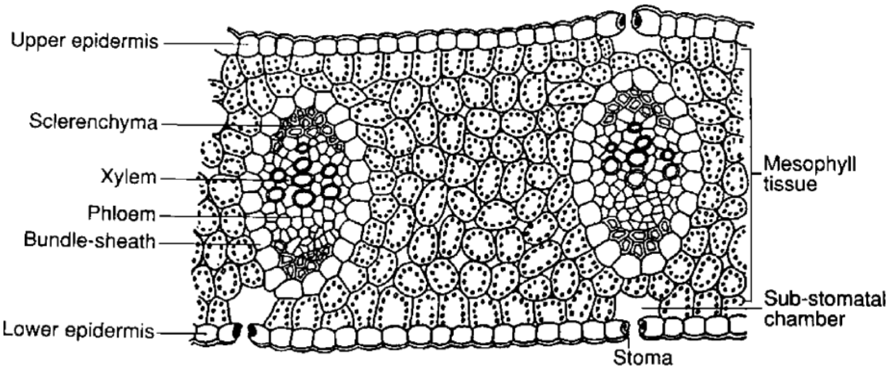


Fig.16: Transverse section of a portion of a *Polianthes* (tuberose) leaf

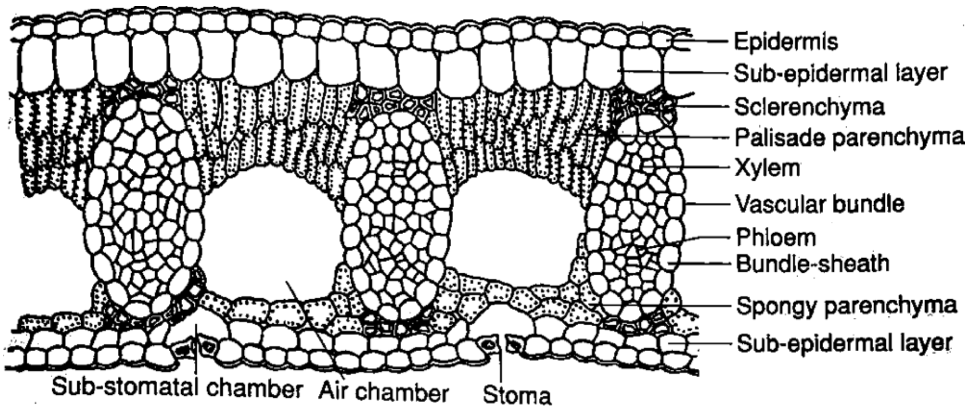


Fig.17: Transverse section of a portion of a *Musa* leaf

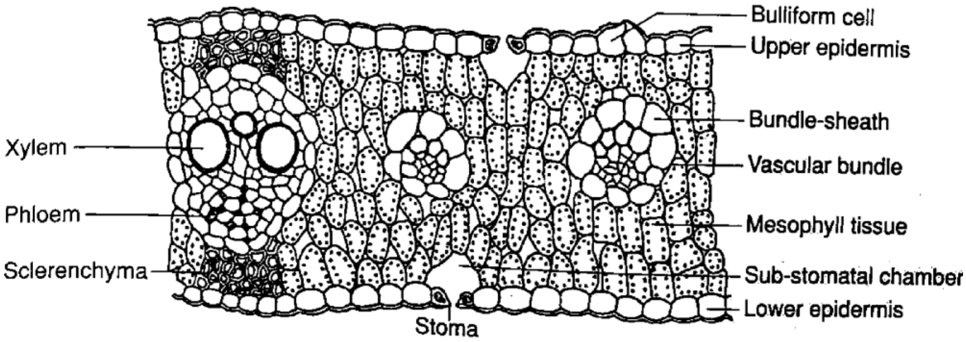


Fig.18: Transverse section of a portion of a *Zea* (maize) leaf

outer wall of the epidermal cell is cuticularized. Stomata are confined to both the epidermal layers. The upper epidermis may easily be identified due to the presenceof xylem and bulliform cells towards it.

Mesophyll:
As the leaf is isobilateral, the mesophyll is not differentiated into palisade and spongy tissues. It is composed of compactly arranged, thin-walled, isodiametric chlorophyllous cells having well-developed intercellular spaces among them.

Vascular bundles:
The vascular bundles are collateral and closed, as found in monocotyledonous stems. Most of the bundles are smaller in size, but fairly larger bundles also occur at regular intervals. The xylem is found towards the upper side and phloem towards the lower side in the bundles. Usually, each bundle remains surrounded by a bundle sheath made up of thin-walled parenchyma cells. The bundle sheath cells generally contain starch grains in them. Xylem consists of vessels and phloem of sieve tubes and companion cells. Sclerenchyma cells occur in patches on both ends of the large vascular bundles which give mechanical support to the leaf.

Summary

The study of the distinctive anatomical characters of both dicotyledonous and monocotyledonous roots can easily be used to understand the relation of xylem, nature of pith, pericycle, etc. In the case of dicotyledonous stems, vascular bundles remain in a ring-like manner. On the other hand, in the case of monocotyledonous stems, vascular bundles remain scattered within the ground tissue of the stem. In dicotyledonous stem, vascular bundles are conjoint, collateral and open. Xylem is endarch. In monocotyledonous stem, vascular bundles remain scattered within the ground tissue. Vascular bundles are collateral and closed. Xylem is endarch.

From the study of the internal structure of dicotyledonous and monocotyledonous leaves, it is observed that there is great diversification of the cells and tissue arrangement in both dorsiventral and isobilateral leaves.

Questions

1. Draw and describe the anatomical structure of a dicot root as seen under transverse section.
2. With suitable drawing and labelling, describe the structure of a monocotyledonous root as seen under transverse section.

3. Write notes on the following:
   (a) Endodermis of monocot and dicot roots;
   (b) Stelar part of dicotyledonous and monocotyledonous root; and
   (c) Draw and describe the nature of epidermis and pericycle of both dicot and monocot roots.
4. How does a monocot stem differ from a dicot stem by their internal structure? Draw, label and describe the internal structures of a typical monocotyledonous stem as found in transverse section.
5. What is starch sheath? Draw, label and describe the typical internal structure of a dicotyledonous stem as found in transverse section.
6. Write notes on the following:
   (a) Vascular bundle in dicotyledonous stem;
   (b) Vascular bundle in a typical monocotyledonous stem;
   (c) Collenchyma cells in dicotyledonous stem;
   (d) Distinctive and characteristic features of monocotyledonous stem.
7. With labelled diagram as found in transverse, describe the internal structure of a dorsiventral leaf.
8. With labelled diagram, describe the internal structure of a typical monocotyledonous leaf as found in transverse section.
9. Distinguish and compare the following pairs:
   (a) Epidermis of dicotyledonous and monocotyledonous leaves;
   (b) Mesophyll of both dicotyledonous and monocotyledonous leaves; and
   (c) Vascular bundles of dorsiventral and isobilateral leaves.

Answers

1. See article no. 2.2
2. See article no. 2.3
3. See article no. 2.2 & 2.3
4. See article no. 2.4 & 2.5
5. See article no. 2.4
6. See article no. 2.4 & 2.5
7. See article no. 2.6
8. See article no. 2.7
9. See article no. 2.6 & 2.7

Unit 4: Secondary Growth: Vascular Cambium

Structure

4.0 Objective

From this unit learners will be able to discuss about the structure and function of vascular cambium. Learners can explain the seasonal activity of vascular cambium.

4.1 Introduction

Cambium is a lateral meristem cell and the cells of which are present in a layer or strip or cylinder at stelar or extra stelar region mainly with periclinal mode of cell divisions.

Meristematic cambium cells in between the primary phloem and primary xylem of open collateral vascular bundles are known as 'Vascular' cambium or 'Fascicula' cambium. Vascular meristem is the primary meristem.

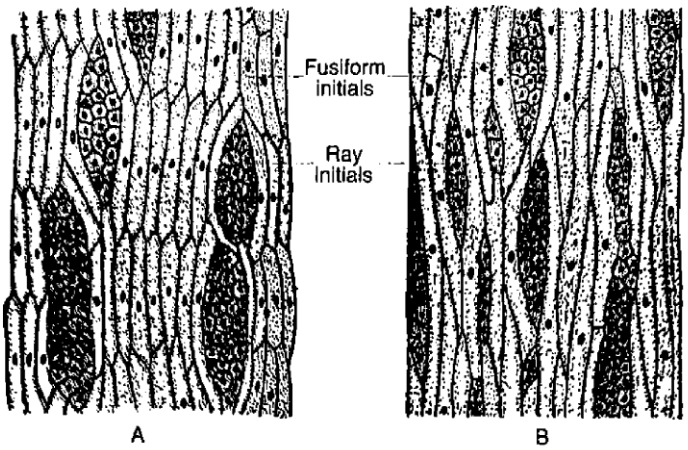
Secondary growth takes place in stems and roots of dicotyledonous plants. Such growth in the stele, by addition of secondary xylem and phloem due to the activity of vascular cambium, is called extra stellar secondary growth. When secondary growth takes place outside the stele, by the activity of cork cambium, it is called extra stelar secondary growth. Extra stelar secondary growth produces periderm.

Structure and function of Vascular Cambium

Cambial cells are generally thin-walled, highly vacuolated and with thin peripheral cytoplasm, with large nucleus; and their radial call walls are much thicker than tangential walls. In thin-walled cells of the cambium many ribosomes and dictyosomes and well developed endoplasmic reticulum are present.

Cambial cells are of two types such as (i) the fusiform initials, which are spindle-shaped and elongated with tapering ends, and (ii) ray initials, which are much smaller than the fusiform initials and with isodiametric to slightly elongated cells.

Ray initials constitute the radial system of the vascular cambium while fusiform initials form the vertical system of the vascular cambium. The size of fusiform initials varies greatly, while the size of the ray initials is more or less uniform. The cells of the cambium ring are either arranged in a single layer or may be of several layers. When the cambium is multilayered the arrangement of the cells may be of two types —
(i) The fusiform initials in horizontal tiers may be arranged so that the ends of the cells in one tier remain more or less at the same level as in another tier. This type is known as storied or stratified cambium.
(ii) Much longer fusiform cells, when ever they do not occur in horizontal tiers and in which the fusiform initials partially overlap with one another at the ends, this type is called non-storied or non-stratified cambium (Fig. 19).



Fusiform initials and ray initials of cambium in longitudinal views : A. Storied cambium. B. Non-storied cambium

Cambium functions by dividing the cell tangentially and forms a new tier of cells. Cells produced by the cambial division, cells at two tiers, and either the external layer matures into secondary phloem while the inner remains as meristematic cambium or the inner layer forms the secondary xylem and the outer remains as cambium. Thus, always there remains a layer of cambium in between the secondary xylem and secondary phloem. The proportion of secondary xylem and phloem remains the same throughout the cambium and thus a cylindrical structure is produced. But the amount of secondary xylem is generally greater than that of secondary phloem.

The cambium cells divide periclinally to add secondary tissues on both inner and outer sides. The outer derivatives are secondary phloem and the inner ones are secondary xylem.

The cambium is composed of two fundamental types of cells viz. (i) fusiform initials and (ii) ray initials. Fusiform initials are fusiform, i.e., elongated, tapered cells, which give rise to the vertical system of secondary tissues. Ray initials are more or less isodiametric and give rise to the horizontal ray parenchyma.

The cambium, here and there, also produces short strips of radially elongated parenchymatous cells on both the inner and outer sides instead of xylem and phloem. These form the secondary medullary rays and are one to few cells in thickness and one to many cells in height. They help in the establishment of connections between the pith and cortex and assist in the translocation of elaborated food matters.

In some monocots like Agave, Dracaena, etc., a type of vascular cambium is present in the peripheral region of the stem. This cambium gives rise to entire vascular bundles comprising both xylem and phloem on the inner side, and the parenchymatous tissue on the outer side. Here, the cells of the cambium region may be fusiform, rectangular or polygonal and even may vary in a single plant.

Seasonal activity of vascular cambium

The cambium remains active throughout the entire life of plants that are growing in tropical regions. Activity of the cambium fluctuates with the fluctuations of the atmosphere. In spring, the cambium forms xylem vessels with wide cavities. This is known as spring wood or early wood. The inactive period of vegetative growth of the plants is in winter and the cambium forms vessels of smaller diameter. This is called autumn wood or late wood. Two types of vessels of this nature together form an annual ring, which represents one year’s growth. The age of a plant can roughly be determined by counting the total number of annual rings, and this process of counting the age is known as dendrochronology. On the other hand, from an anatomical point of view, according to Fahn (1982), the activity of cambial cells takes place in two stages: (i) initially the cambial cells become wider radially, and (ii) secondly the cells begin to divide. The radial walls of cambial cells usually become weakened with the enlargement of their cells. In this stage, the bark of stems and roots may be peeled easily. In later stages, this easy separation of the bark from the xylem is also possible due to an increase in the number of cells in the cambial zone through cell divisions. The separation mainly takes place in the region of young xylem cells that have reached their maximum diameter but still have their primary walls.

Important natural activity of cambium

(1) Cambium always produces secondary xylem towards the inner side and secondary phloem towards the outer side.

(2) It is always produced at a particular position. In a wounded stem, new cambium is always formed beneath and parallel to the exposed surface, and the new cambium completes the broken cylinder.

(3) More or less homogeneous cells of cambium produce a complex tissue having different types, i.e., heterogeneous cells.

(4) Activity of cambium is seasonal and different growth layers are formed due to this seasonal activity, and these growth layers appear as rings in transverse section and are known as growth rings.

(5) Response to gravity: The lower side of a horizontal shoot of Pinus shows increased secondary growth, and this increased secondary growth is due to gravity; this type of wood is known as reaction wood. It is developed on leaning trunks or branches.

(6) Reaction to day length: In plants like Robinia, long-day treatment produces all early wood with wide vessel members, but short-day treatment produces all late wood with a few narrow vessel members.

(7) Reaction to wind: In places where wind blows in a particular direction, the activity of cambium in response to this wind blow is observed as the secondary growth being directed towards two sides. This type of activity of cambium produces wood, and that is known as compression wood. The reaction wood of the conifers is also termed as compression wood, and that of the dicotyledons as tension wood. Tension wood develops on the upper side of leaning dicotyledonous stems and is similar to compression wood. Tension woods are distinguishable as two types: (i) compact tension wood, in which the gelatinous fibres are from continuous regions (e.g., Acer) and (ii) diffuse tension wood, in which single or groups of gelatinous fibres are scattered among the normal fibres (e.g., Acacia).

(8) Response to water: According to Shephards et al., light moisture content causes more rapid cambial activity.

4.4 Summary

The vascular cambium is a lateral meristem responsible for secondary growth in plants, contributing to the increase in girth of stems and roots. It is primarily found in dicots, gymnosperms, and certain other vascular plants but is absent in monocots and specific angiosperm (e.g. Podostemaceae and Nymphaeales). It forms a cylindrical layer of meristematic cells between the primary xylem (inward) and primary phloem (outward). It produces secondary xylem (wood) on the inside and secondary phloem on the outside, pushing the primary tissues apart. Fusiform initials and Ray initials are two main cell types of it. In herbaceous plants, it appears as discontinuous vascular bundles, while in woody plants, it forms a continuous ring.

4.5 Questions

1. Write in details about vascular cambium and the function and structure of vascular cambium.
2. Describe secondary activity of cambium and mention the important natural activity of cambium.

4.6 Answers

7. Seearticleno.4.2
8. Seearticleno.4.3& 4.3.1

Unit 5: Secondary Growth: Root and Stem

5.0 Objective

From this unit learners will be able to know about the secondary growth found in root and stem .

5.1 Introduction

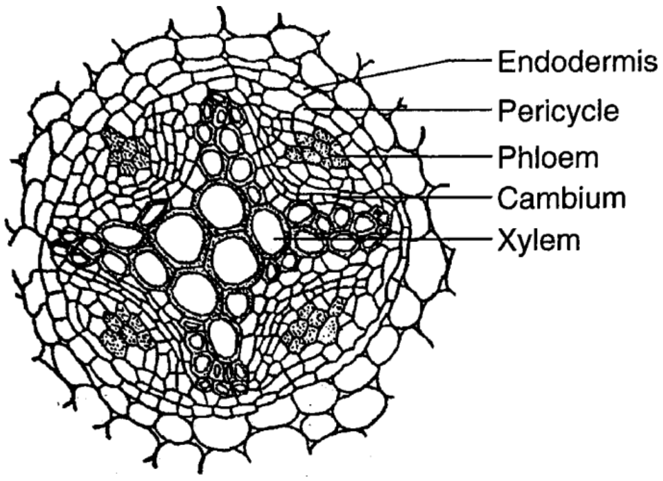
Secondary growth takes place in stems and roots of dicotyledonous plants. Such growth in the stele, by addition of secondary xylem and phloem due to the activity of vascular cambium, is called extra stellar secondary growth.When secondary growth takes place outside the stele, by the activity of cork cambium, it is called extra stelar secondary growth. Extra stelar secondary growth produces periderm.

Secondary growth in roots and stems

The increase in thickness due to the formation of secondary tissue by the activity of cambium and cork cambium is known as secondary growth.

Secondary growth in dicotyledonous roots

In woody and herbaceous dicotyledonous plants, roots undergo secondary increase in thickness by the formation of secondary meristem. As the cambium is absent in roots, the secondary growth in roots is of special interest. The dicotyledonous roots possess a limited number of radial vascular bundles with exarch xylem. On the initiation of secondary growth, a few parenchyma cells beneath a group of phloem become meristematic and thus as many cambial strips are formed as the number of phloem groups. Some of the cells of a single-layered pericycle become meristematic, lying against the protoxylem groups,
which divide and form a few layers of cells. The first formed cambium now extends towards both of its edges and reaches the innermost derivatives of the pericycle, thus giving rise to a complete ring of cambium (Fig. 20). The cambium ring is wavy in outline as it passes internal to phloem and external to xylem. The cambial cells, as a rule, cut more xylem cells than phloem cells. The first formed cambium produces secondary xylem much earlier and the wavy cambium ring ultimately becomes circular. Now the whole of the cambium ring becomes actively meristematic and behaves in a normal manner, i.e., giving rise to secondary xylem on its inner side and secondary phloem on its outer side. The secondary xylem gets embedded in it (Fig. 21). At this stage, distinction can be made only by exarch primary xylem located in the centre. The primary phloem elements are usually seen in a crushed condition. The cambial cells which originated from the pericycle lying against the groups of protoxylem function as ray initials and produce broad vascular rays. These rays are traversed in the xylem and phloem through cambium, and this is the characteristic feature of the root. The single-layered pericycle becomes meristematic and divides, giving rise to cork cambium or phellogen. It produces a few brownish layers of cork cells of phellogen towards the outside and probably the phelloderm on the inside. The pressure caused by secondary tissues ruptures the cortex with endodermis, which is ultimately sloughed off. Epiblema dies out earlier. Lenticels may also be formed (Fig. 22).



Early stages of secondary growth in a dicotyledonous root showing formation of the wavy cambium cylinder.

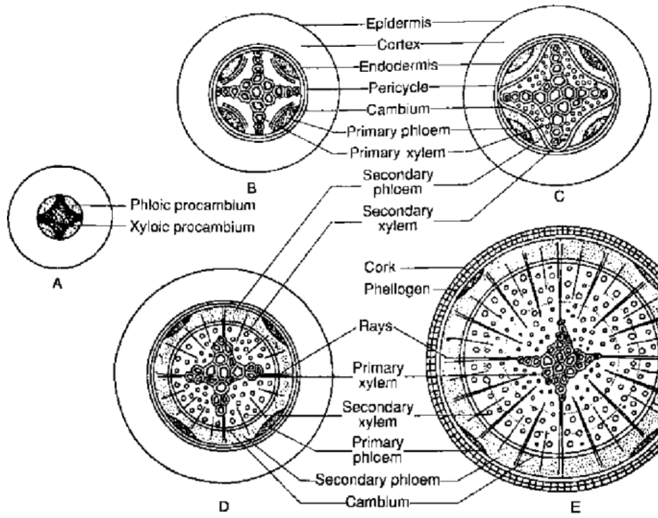


Fig.21: Diagrammatic view of the stages of secondary growth in thickness in dicotyledonous root

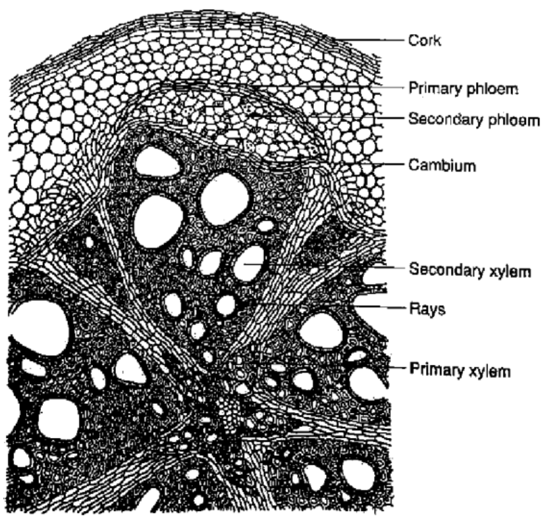


Fig.22: Cellular view of a portion of *Tinospora* root showing secondary growth in thickness

Secondary growth in dicotyledonous stem

The growth in thickness in stems and roots of plants by the activity of cambium after the cessation of primary growth is called secondary growth.

Secondary growth takes place in stems and roots of dicotyledonous plants. Such growth in the stele, by addition of secondary xylem and phloem due to the activity of vascular cambium, is called intrastelar secondary growth. When secondary growth takes place outside the stele, by the activity of cork cambium, it is called extrastelar secondary growth. Extrastelar secondary growth produces periderm.

Intrastelar secondary growth in stem

Secondary growth in dicotyledonous stems takes place by the activity of meristematic cambium in between the primary phloem and primary xylem of open collateral vascular bundles. As vascular bundles are arranged in a ring, the cambium of the vascular bundle can be united laterally by the newly formed cambium strips to form a cambium ring.

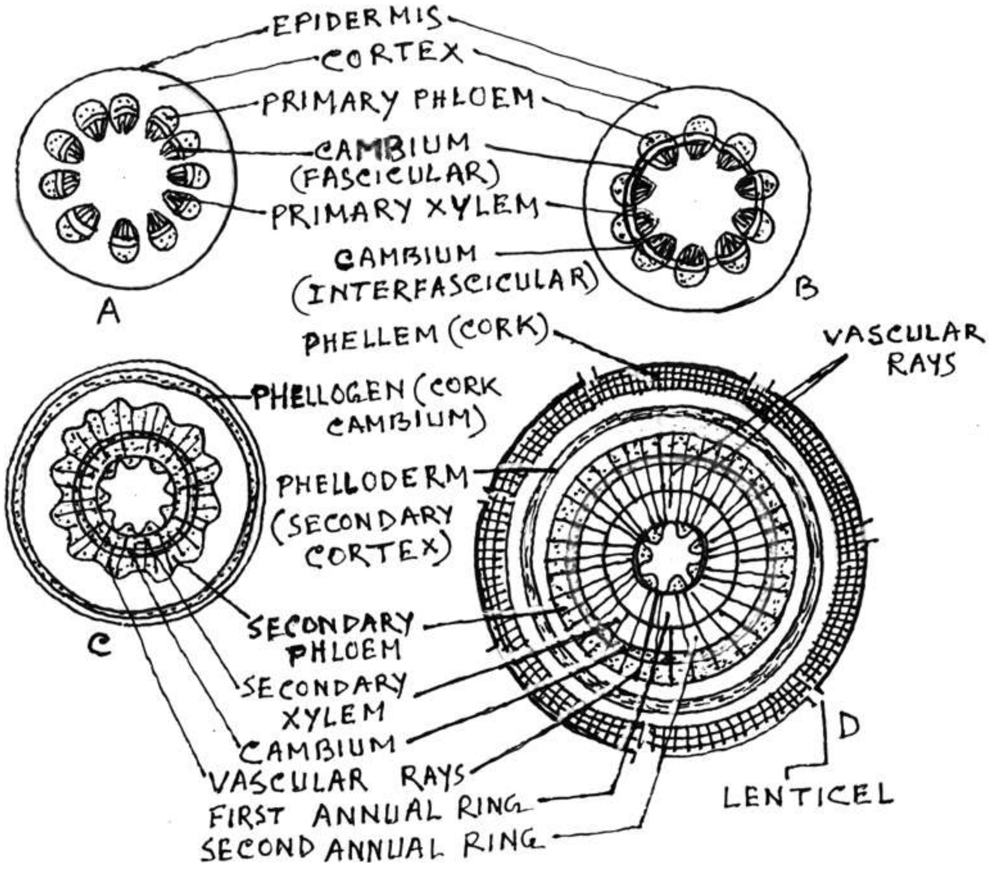


Fig.23: Secondary growth in thickness.A-D,diagrams showing stages in the secondary growth of a dicotyledonous stem.

The cambium in the vascular bundles are known as ‘fascicular’ cambium which is a primary meristem. At the onset of secondary growth, new cambium strips develop on the lateral side of the fascicular cambia by division of parenchymatous medullary ray cells. These are known as ‘interfascicular’ cambium, a secondary meristem which joins the fascicular cambia to form a cambium ring. The cambium ring then divides repeatedly and periclinally to form tissues on both the outer and inner sides of the cambium. The outer secondary tissues are secondary phloem and the inner tissues are secondary xylem (Fig. 23). The primary xylem and phloem, although distinguishable, become crushed in the later stages. In this way, a complete ring of xylem and phloem tissues are formed on the inner and outer side of the cambium ring respectively (Fig. 23).

Secondary xylem, which is produced by the activity of the cambium, possesses four different kinds of elements viz. tracheids, vessels, xylem fibre and xylem parenchyma. Tracheids, vessels and xylem fibres form the vertical system. Xylem parenchyma are of two types such as the vascular parenchyma, which is the vertical system, and ray parenchyma, which is the horizontal system.

The secondary phloem is composed of sieve tubes, companion cells, phloem fibre or bast fibre and phloem parenchyma.

With greater production of secondary xylem and phloem, the primary xylem is pushed towards the centre and the pith is crushed. Finally, the central part of the stem is occupied by secondary wood. The primary phloem is pushed outward and may be crushed. The endodermis and pericycle disintegrate. Even the epidermis and some peripheral parts of the cortex are ruptured.

The cambium, here and there, also produces short strips of radially elongated parenchymatous cells on both the inner and outer sides instead of xylem and phloem. These form the secondary medullary rays, and are one to a few cells in thickness and one to many cells in height. These cells help in the establishment of connections between the pith and cortex and help in the translocation of elaborated food matters.

Activity of the cambium fluctuates with the fluctuation of the atmosphere. In spring or summer, the cambium is more active and forms a greater number of vessels with wider cavities. This is known as spring wood or early wood. In winter, i.e., the inactive period of vegetative growth of the plant, the cambium forms vessels of small diameter. Moreover, tracheids and fibres are also formed from this less active cambium. This is called autumn wood or late wood. However, the line of demarcation is quite conspicuous between the late wood of one year and the early wood of the next year. Two types of wood of this nature together form an annual ring and represent one year’s growth. The age of a plant can roughly be determined by counting the total number of annual rings, and this process of counting the age is known as dendrochronology.

Extrastelar secondary growth

As a result of extensive intrastelar secondary growth, a pressure is exerted on the epidermis and the peripheral part of the cortex from the central part. Consequently, the epidermis and also some outer part of the cortex of the stem are ruptured. This wound may expose the inner tissue to infection and desiccation. To avoid this situation, periderm formation takes place beneath this zone of tissue.

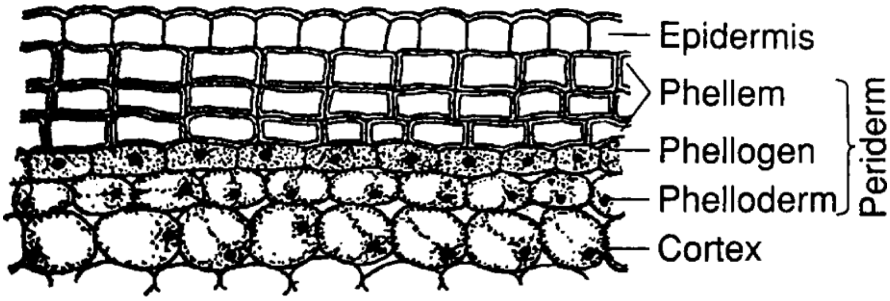


Fig.24: Diagram showing periderm formation

The parenchyma cells beneath the ruptured part divide tangentially and form a cambium, and that cambium is known as cork cambium or phellogen. Phellogen gives cork tissues or phellem towards the outside and a thin layer of phelloderm towards the inner side. The phellem, phellogen and phelloderm together is known as periderm (Fig. 24).

Phellem or cork cells are dead, rectangular, compactly arranged, thick-walled, suberized cells and so the cork layer is impervious to fluids and gases. So the cork of Quercus sp. (Fagaceae) is used for stopper of bottles and also used as commercial cork. The phelloderm is composed of one or few layers of living parenchymatous cells.

When periderm or cork is formed in the subepidermal region or deep in the cortex, the living tissues outside it are devoid of a supply of water and nutrition, and as a result the tissue dies and dries up forming a bark outside the cork.

When the diameter of the stem is increased gradually, the rupturing of the exterior tissues takes place including the earlier periderm layers and are reformed deeper and deeper in the stem. Such successive and overlapping layers of cork form the rhytidome or shell bark or scale bark and detach in the form of scales.

Sometimes the periderm causes the shedding of the bark in sheets, as in Vitis. Such abscission is due to the formation of thin-walled lignified cells beneath the firm layers of cork. It is known as ring bark.

With the formation of extensive periderm the protective function is maintained, but the cork tissues being impervious to gases, the gaseous exchange between the inner tissue and the external atmosphere becomes difficult. Some pores like raised spots develop there to facilitate gaseous exchange. These are called lenticels.

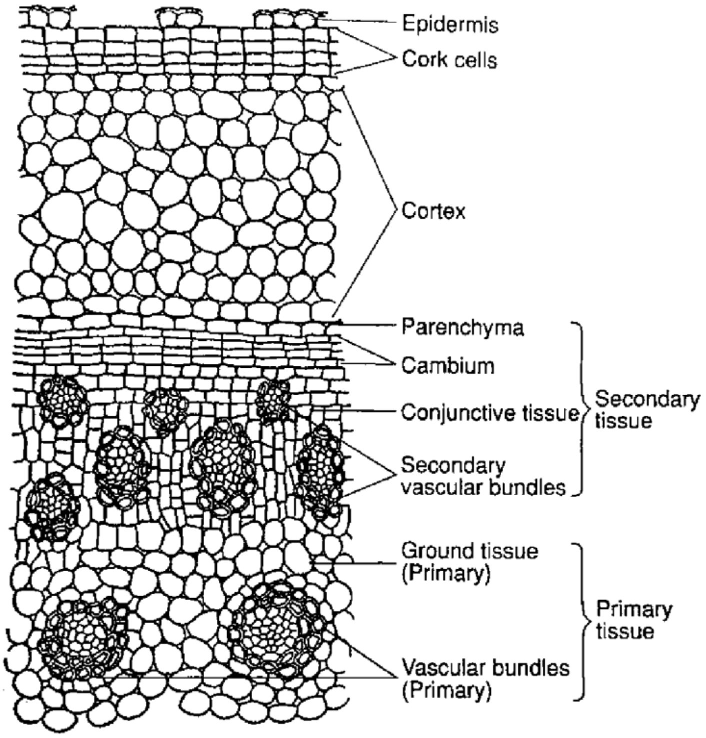
During the development, the cork cambium instead of producing cork cells produces loosely arranged parenchymatous cells known as complementary cells. These cells possess profuse intercellular spaces which permit gaseous diffusion. The complementary cells are bounded externally by some more compactly and densely arranged cells, called closing cells. This closing layer later breaks by the extensive development of complementary tissues.

Secondary growth in Monocot stem

Normally, secondary growth by the activity of cambium does not take place in monocotyledonous stem because the primary vascular bundles are of closed type. But in certain plants of Liliaceae viz. Dracaena, Yucca, Aloe, Agave, Cordyline, etc., secondary growth takes place in stem due to some accessory cambium.

In Dracaena, the primary vascular bundles are leptocentric type and scattered in the ground tissue. An accessory cambium develops outer to the primary vascular bundle and gives rise to secondary leptocentric vascular bundles. These secondary vascular bundles remain embedded in a secondary conjunctive tissue (Fig. 25). The conjunctive tissues are composed of thin-walled, rectangular cells, closely arranged, without having any intercellular spaces. Sometimes these tissues become thick-walled in some plants.

Typical periderm formation by the activity of phellogen, although lacking in monocot stem, is replaced by storied cork cells forming a protective tissue. These are formed by the continuous periclinal division of peripheral cortical parenchyma cells and their suberization.



Cellular diagram of a portion of *Dracaena* stem in T.S. showing special type of secondary growth

Wood (Heartwood and Sapwood)

In mature stems, where sufficient amount of secondary growth has taken place, the secondary wood loses the power of conduction and its cells are filled with tannins and other substances. It becomes hard and durable, darkened in colour, and is composed of dead xylem elements. This region is termed as heartwood. This type of wood is mainly concerned with support. The outer region of secondary xylem or wood, which consists of younger xylem cells, is lighter in colour and is composed of living parenchyma cells of the wood in addition to tracheary elements and fibres; this is known as sapwood. It is concerned with the conduction of water and salt solutions from the root to the leaf. Moreover, it helps in storage of food and support (Fig. 23a).

Sapwood is gradually converted to heartwood. Conversion of heartwood from sapwood involves the following changes: (i) The loss of protoplast is in the living cells.

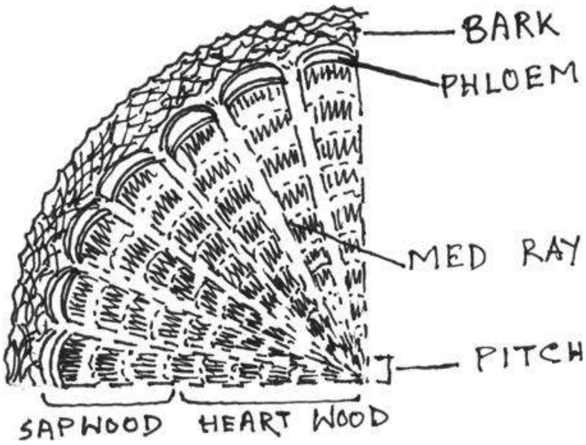


Fig.23a: Transections of old dicot stems section showing heartwood and sopwood

(ii) The cells appear withdrawn and the water content of the cell wall is much reduced.
(iii) Tyloses are developed, blocking the cavities, and the walls of the parenchyma cells become lignified.
(iv) Some substances like oils, gums, resins, tannins and colouring matters are deposited on the cell walls and cavities of the elements.

The quantitative relation between the amount of heartwood and sapwood and the degree of differences between them are variable in different plants and such differences are usually influenced by the conditions under which the plants are grown. From the commercial viewpoint, the heartwood is more durable and forms the timber of commerce.

5.5 Summary

Through the study of secondary growth of both root and stem, it can easily be concluded that the nature of cambium activity, its function, wood formation in plants can well be understood. More over intrastelar and extrastelar secondary growth i.e. attaining of thickness in girth roots and stem takes place by the formation of secondary xylem elements and bark formation in woody plants is solely responsible for periderm formation.

5.6 Questions

3. With suitable labeled diagram describe the secondary growth of a dicot stem.
4. Write notes on the following:
   (a) Extra stellar secondary growth in stem.
   (b) Heart wood and sap wood.

5.7 Answers

1. See article no. 5.3
2. See article no.5.3.1 & 5.4

Unit 6: Adaptive and Protective System

6.0 Objective

- This unit gives learners a clear knowledge about the adaptive and protective systems of plants in relation to environmental conditions.
- Learners will be able to discuss about the different protective covering of the plant mainly epidermis, cuticle and stomata.
- Learners can describe the adaptive nature of xerophytes and hydrophytes.

4.1 Introduction

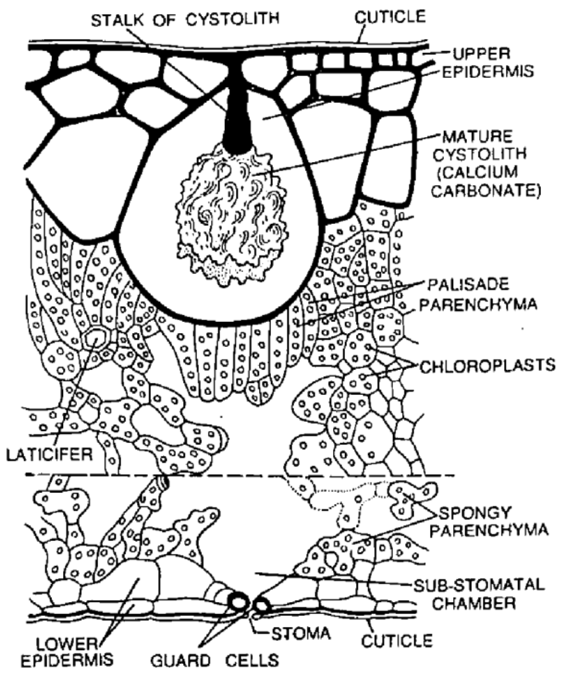
Plants are with protective and adaptive systems of their own according to the conditions of environment which are far from normal. The dermal system forms the outer protective covering of the different organs of the plant and is represented in the primary plant body by the epidermis, cuticle and stomata etc. In addition to these there are also the presence of the hairs, bulliform cells, hydathodes, etc. may also act as protective in nature.

Protective coverings of the plant body

Epidermis

The dermal system forms the outer protective covering of the plant and is represented by the epidermis. The outer protective covering of the plant body—the epidermis, cuticle and stomata—is provided by the epidermis in the primary plant body. During secondary growth, the epidermis may be replaced by another dermal system, such as the periderm, with the cork cells forming the new protective tissue.

Epidermis is the outermost layer of the plant body. It usually consists of a single layer of parenchymatous cells and is protective in nature. It is a continuous layer



Epidermis. Multiple epidermis in T.S. of *Ficus elastica leaf*. A mature cystolith with calcium carbonate deposited on its stalk in the epidermal cell.

except for certain small pores called stomata and lenticels. The epidermis is mostly one cell-layered thick, but in leaves of many plants like Ficus benghalensis, Ficus elastica, Nerium spp., etc., the epidermis has been described as bi- or multi-cell-layered thick (Fig. 26). The epidermal cells may be somewhat irregular in outline, usually varying in shape and size and arranged very close to each other, having no intercellular spaces among them.

The cells possess a large central vacuole and thin peripheral cytoplasm. The cells may contain leucoplasts, anthocyanins and chromoplasts, but no chloroplasts except in guard cells. In the epidermal cells of certain aquatic and shade-loving plants, chloroplasts are also found. Sometimes, substances like mucilage, tannin and calcium carbonate crystals, i.e., cystoliths, are also found in these cells (Fig. 26).

The walls of epidermal cells are unevenly thickened. The inner and radial walls are comparatively thicker. The additional thickness is due to the impregnation of suberin or cutin. The suberization and cutinization of the walls protect the epidermis from mechanical injuries and prevent water loss.

On the surface of the epidermis, outgrowths are present in the form of hairs and trichomes which are uni- or multi-cellular. In the case of roots, the outermost layer is called epiblema or piliferous layer. Usually, its cells extend outward in the form of tubular unicellular root hairs which help in the absorption of water and mineral nutrients from the soil.

Functions of epidermis

1. The epidermis is primarily a covering layer that helps in the protection of the internal soft tissues against mechanical injury.

2. It prevents excessive evaporation of water from the internal tissues; for this, several adaptations like development of a thick cuticle, wax, hairs, etc. take place.
3. It sometimes helps in photosynthesis and secretion.
4. In many xerophytic plants, the epidermis acts as a storehouse of water.
5. A few epidermal cells develop into the secretory tissues of nectaries, the stomata of leaves and stems, and the absorbing hairs of roots.

Cuticle

Plant cuticle is a protecting film covering the epidermis of leaves, young shoots. The cuticle contains a non-saponifiable hydrocarbon polymer known as cutan.

In some higher plants, the cuticle is a water-impervious protective layer covering the epidermal cells of leaves and other parts, limiting water loss. It consists of cutin, a waxy, water repellent substance allied to suberin, which is found in the cell walls of corky tissue.

Cuticle is a protecting film covering the aerial parts of plant organs without periderm. It consists of lipid and hydrocarbon polymers impregnated with wax and is synthesized exclusively by the epidermal cells. Waxy covering can be found mainly on all exposed surfaces except roots.

Plant cuticle provides protection against desiccation and external environmental stresses.

The aerial parts of land plants are covered by a hydrophobic layer called cuticle that limits non-stomatal water loss and protects against external biotic and abiotic stresses. Fleshy fruits are also covered by the cuticle which has an important protective role during fruit development and ripening.

Stomata

The stomata are minute pores which occur in the epidermis of the various aerial parts, particularly leaves of plants. Each stoma remains surrounded by two kidney-shaped epidermal cells – the guard cells. The stomata may occur on any part of a plant except the roots. The epidermal cells bordering the guard cells are called accessory cells or subsidiary cells.

Generally, the term stoma is applied to the stomatal opening and the guard cells. The guard cells are living and contain chloroplasts in them. They also contain a larger proportion of protoplasm than other epidermal cells. Usually, in the leaves of dicotyledons, the stomata remain scattered, whereas in the leaves of monocotyledons they are arranged in parallel rows. Stomata occur on both the upper and lower surfaces of leaves, but especially they are confined to the lower surface. In floating leaves, stomata are confined only to the upper surface. Under normal conditions, the stomata remain closed in the absence of light or at night, or remain open in the presence of light during the day.

The stoma, i.e., the pore and two guard cells along with the subsidiary cells, is often termed as the stomatal complex.

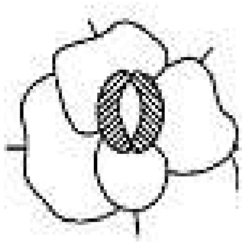
Types of stomata

Different types of stomata are commonly found in different plant groups and these are described below:

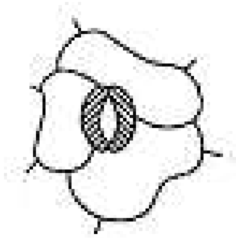
1. **Anomocytic or irregular or Ranunculaceous type:** Here, actual subsidiary cells are absent; each stoma is irregularly surrounded by a certain number of cells which do not differ in size and shape from other epidermal cells. This type is also known as the Ranunculaceous type as seen in members of Ranunculaceae and in many other plants

belonging to Malvaceae, Scrophulariaceae, Papaveraceae, Geraniaceae, etc. e.g., Ranunculus sp., Clematis sp., Cucurbita sp., Vitis sp., etc.

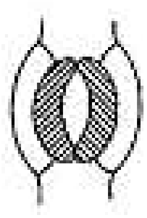
2. **Anisocytic or unequal-celled type or Cruciferous type:** Here each stoma is surrounded by three subsidiary cells, one cell being considerably smaller or larger than the other two. This type is seen in members of Cruciferae, Solanaceae etc., and in Brassica sp., Iberis sp., Solanum sp., Nicotiana sp., Petunia sp., etc.
3. **Paracytic or parallel or Rubiaceous type:** This type of stoma usually has two subsidiary cells parallelly placed to the long axis of the guard cells and the stomatal pore. This type of stoma is present in members of Rubiaceae, Leguminosae, Magnoliaceae, e.g., Gardenia sp., Ixora sp., Phaseolus sp., Magnolia sp., etc.
4. **Diacytic or cross-walled or Caryophyllaceous type:** Here each stoma is surrounded by two subsidiary cells and their common wall is at right angles to the longitudinal axis of the guard cells. This type of stoma can be seen in members of Caryophyllaceae, Acanthaceae, etc., e.g., Dianthus sp., Hygrophila species.
5. **Hemiparacytic:** There is a single subsidiary cell parallely placed or oriented to the long axis of the pore in the stomatal complex. This subsidiary cell may be long or short in length in contrast to the guard cells, e.g., Tetracentron sp.
6. **Actinocytic:** In this stomatal complex the two guard cells remain surrounded by four or more radially arranged elongated subsidiary cells, e.g., Ancistrocladus sp.
7. **Cyclocytic:** Here the stoma remains surrounded by four or more subsidiary cells arranged in a narrow ring around the guard cells, e.g., Lumnitzera sp. and Laguncularia sp., etc.
8. **Tetracytic:** This type shows four subsidiary cells surrounding the guard cells, with two subsidiary cells remaining on the polar sides and the other two on the lateral sides of the guard cells, as found in Rhodosp.
9. **Hexacytic:** Here six subsidiary cells present surround the guard cells. Two of them are situated on the two polar sides and the remaining four subsidiary cells occur on the two lateral sides, in parallel to the long axis of the guard cells and the aperture. This type is present in many species of Palmae, Pandanaceae and Cyclanthaceae.



Anomocytic



Anisocytic



Paracytic

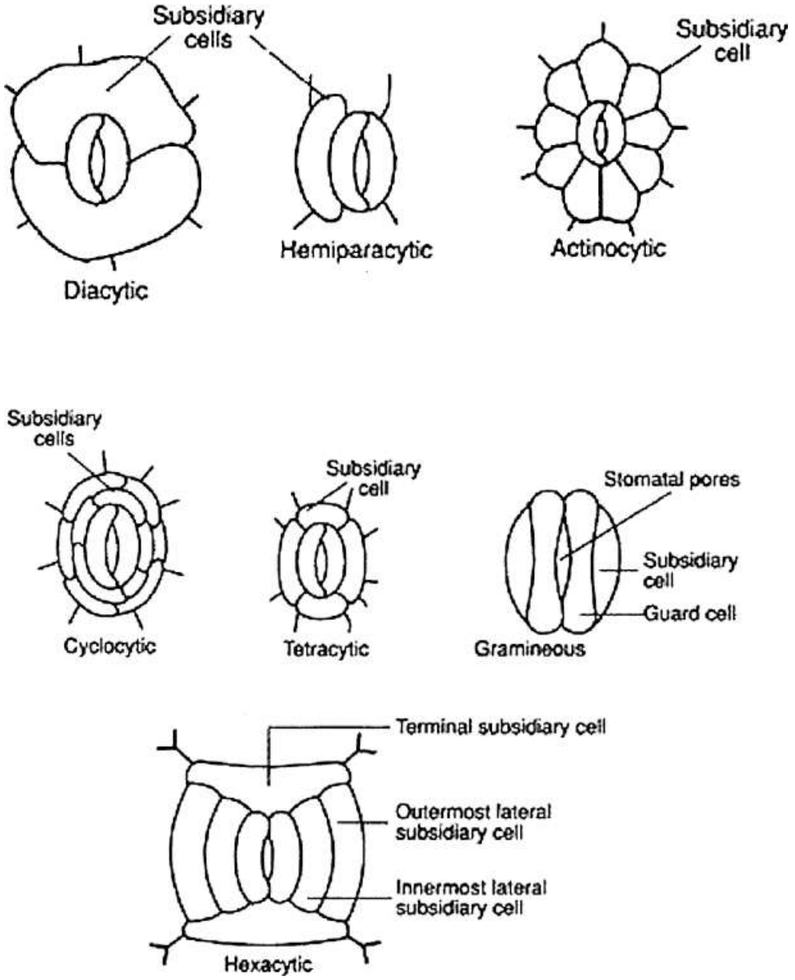
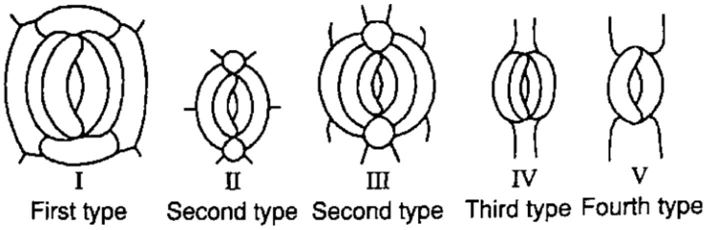


Fig.27a: Drawings representing different types of stomata

10. Graminaceous: Metcalfe and Chalk described this type of stomata found in monocot leaves. It is the characteristic of the families Gramineae and Cyperaceae. Here, the guard cells are dumb-bell-shaped or osteate, whose two attached ends are bulbous and the middle parts are much narrower and straight, resembling dumb-bells. In the narrow portion, the cell wall is highly thickened, whereas the bulbous ends are relatively thin-walled. The subsidiary cells occur parallel to the long axis of the pore.
    e.g., Oryza sativa, Zea mays.

Four types of stomatal complex in monocotyledons based on Stebbins and Khush (1961)

1. **First type:**
   Here, the guard cells remain surrounded by 4 subsidiary cells—two at the polar sides and two at the lateral sides—giving a square-like appearance in surface view, e.g., Tradescantia sp., Rhoeo sp.
   In Commelina sp., subsidiary cells are six, of which four are situated on the two lateral sides and the remaining two at the polar sides of the guard cells.
2. **Second type:**
   Here also there are 4–6 subsidiary cells and out of them, two are rounded and smaller in size, each lying at each pole. The remaining four are arranged on the lateral sides, e.g., Pandanus haerbachii, members of Palmae and Cyclanthaceae. Caryota and Calamus of Palmae, however, have two subsidiary cells only on the two lateral sides of the guard cells.
3. **Third type:**
   Here, the two guard cells of a stoma are surrounded by two subsidiary cells, each remaining on the lateral sides of a guard cell, e.g., Juncus effusus. This is the most predominant type of stomatal complex found in many monocot families such as Gramineae, Cyperaceae, Typhaceae, Juncaceae, etc.
4. **Fourth type:**
   In this type, the stomatal complex is formed without any subsidiary cells. This is also a very common type found in families such as Amaryllidaceae, Iridaceae, Orchidaceae, Agavaceae, etc.



Diagrammatic drawing representing types of stomata according to Stebbins and Khush (1961)

Types of stomata based on ontogeny after Pant (1965)

(a) Mesogenous: In this type the subsidiary cells have a common origin with the guard cells, i.e., both are developing from the same meristemoid.

(b) Perigenous: Here the subsidiary cells do not have a common origin with the guard cells; instead, subsidiary cells are formed by cells lying around the meristemoid that divides to form the guard cells.

(c) Mesoperigenous: In this type, at least one of the subsidiary cells has a common origin with the guard cells, but others do not have a common origin.

Functions of stomata:
On the physiological point of view, stomata are very important and the functions of stomata are as follows:
(i) To take part in gaseous exchange between plant organs and the atmosphere during respiration and photosynthesis.
(ii) To eliminate excess water absorbed by the root system by the process of transpiration.
(iii) To carry out photosynthesis in the guard cells due to the presence of chloroplasts.

General account of adaptation in xerophytes and hydrophytes

Introduction

Xerophytes are the plants of relatively dry habitats in soil. The xerophytic plants are desert living and they adapt themselves to grow on places where there are (i) scarcity of water, (ii) abundance of soluble salts in the soil, (iii) richness of humic acid and (iv) intense illumination. In order to endure the dry conditions, the xerophytic plants must adopt all the means at their disposal, aiming constantly at two definite objectives:
(i) to procure as much water as they can get from the inhospitable soil, and
(ii) to economise on this supply of water by conservative use and keeping the loss of water from the shoot and the water requirement of the plant to a minimum.

These adaptations are found in all the characters of the plants—morphological, anatomical as well as physiological. Plants growing on rocks, sandhills, table lands, deserts, alpine peaks, etc., show similar features due to obvious reasons. Hence, in xerophytes, the adaptations are in relation to the scarce supply of water.

Hydrophytes include those groups of plants which are normally growing in swampy or marshy habitats containing a quantity of water which would prove much more than optimal for average plants. Due to their aquatic habit, they modify their morphological and anatomical structures and even their physiological characters.

Adaptive features of xerophytic plants – Morphological adaptations

Roots:

(i) Xerophytic plants have a well-developed root system. In certain cases, roots are much elongated than those of the stem or aerial parts.
(ii) Roots are elongated and primary roots are of the tap root type. Roots are highly branched and grow in a widespread zone.
(iii) Root hairs and root cap are well developed.

Stems:

(i) Stems are usually dwarf, woody, dry, rigid and with thick bark.

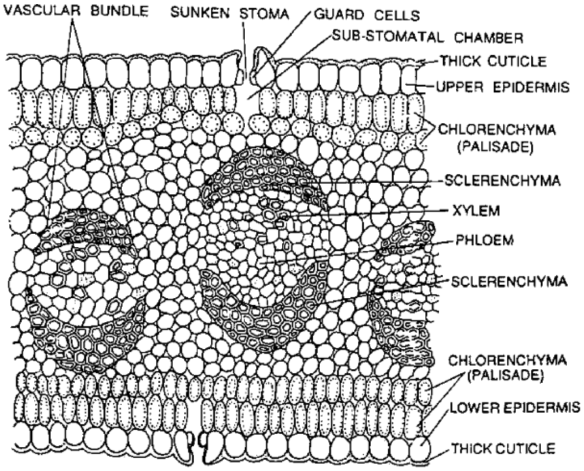
(ii) In a few cases, the stem is rhizomatous as in Saccharum officinarum.
(iii) Sometimes stems are fleshy, juicy, and green like that of leaves, known as phylloclades (e.g., Opuntia dillenii).
(iv) Stems are with hairs or with a waxy covering.

Leaves:
(i) Leaves are small and transform into scale leaves and persist for a short period.
(ii) In a few cases, the leaves transform into spines, as for example the phylloclades remain covered with spines.
(iii) In Pinus sp., leaves are long and needle-shaped.
(iv) In Acacia nilotica, leaves are compound with leaflets.
(v) When leaves persist, they are thick, fleshy and become leathery.
(vi) Leaves are smooth and glossy to reflect sunlight.
(vii) Leaf margins of a few monocotyledonous plants like Ammophila sp., Agropyron sp. are folded in such a manner that sunken stomata remain hidden, thus reducing the rate of transpiration.
(viii) In the case of Acacia nilotica, Ziziphus mauritiana the stipules are transformed into spines.

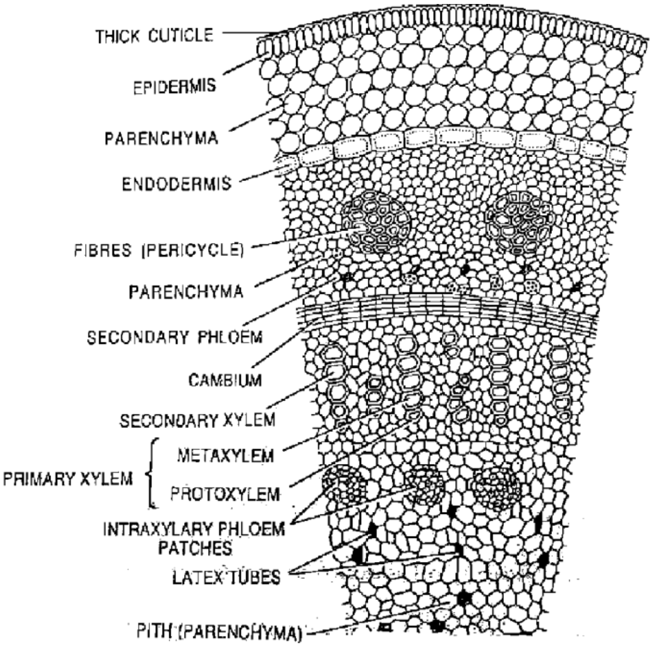
Anatomical adaptation

Roots:
(i) Root hairs and root cap are well developed and in the case of Opuntia dillenii root hairs are present up to the root tip.
(ii) In Asparagus racemosus, roots are swollen and have water storage tissue.
(iii) The cell wall of the root is rigid and thick.

Stem:
(i) Water storage tissues are present in the fleshy xerophytic stem (e.g., Aloe barbadensis).
(ii) The fleshy xerophytic stem is with a thick cuticle.
(iii) The epidermis is well developed and its cell wall has a thick cuticle.
(iv) The hypodermis is multilayered and is constituted of sclerenchyma.
(v) Sunken type of stomata are present.
(vi) Vascular tissues are well developed, clearly visible and vascular bundles are with a multilayered bundle sheath (Fig. 28).
(vii) Mechanical tissues are well developed (Fig. 29).
(viii) Barks are well constructed.
(ix) Oil glands and resin canals are often present.



Anatomy of xerophytic leaf. V.S. of leaf of *Agave* (monocot) showing detailed structure.



Anatomy of xerophytic stem. T.S. of a sector of *Calotropis* stem (dicot.)—detailed structure.

Leaves

(i) Epidermal cells of fleshy leaves act as water storage tissue, e.g., Peperomia pellucida.

(ii) Water remains stored in leaf mesophyll tissues as in Aloe sp. and Salsola sp.

(iii) Presence of thick cuticle and cuticle along with cellulose remain present on epidermal cell wall.

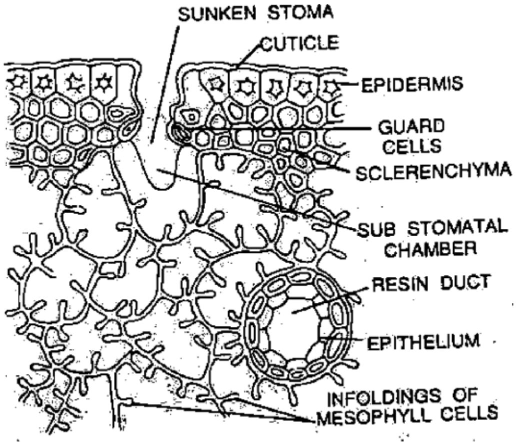
(iv) Thick cuticle is present on the leaves of fleshy xerophytic plants such as Nerium oleander, and Pinus sp.

(v) Epidermis is multilayered and hypodermis is made up of sclerenchyma tissue.

(vi) Mesophyll tissue is divisible into spongy and palisade tissue.

(vii) Stomata are sunken and remain restricted on the lower epidermis. Stomata present in stomatal pits are surrounded by hairs in the leaves of Nerium sp.

(viii) Mechanical tissue is well developed. Transfusion tissue is present in the leaves of Pinus sp. along with sunken stomata (Fig. 30).



Structure of xerophytic leaf (microphyllous type). C.S. of a marginal part of leaf of *Pinus nigra.*

Physiological adaptation

(i) Rate of transpiration is very low.

(ii) Certain plants like *Solanum virginianum* (*S. surratensis*) complete their life cycle in a very short span of time; this is known as an ephemeral plant.

(iii) Osmotic pressure is very high in xerophytic group of plants.

(iv) Draught enduring resistance is very much pronounced in xerophytic plants.

(v) Enzyme-like catalase and peroxidase are very much active.

Adaptive features in hydrophytic plants – Morphological adaptation

Root:

(i) Mostly the roots are absent, e.g., *Wolffia* or *Rhizocaulon* (or *Rhiza*), *Ceratophyllum demersum*.

(ii) Roots, if present, then these are scanty as in *Hydrilla verticillata*.

(iii) A large amount of roots are present in the plants growing in mud, e.g., *Ranunculus sceleratus*.

(iv) Roots are devoid of root hairs; if present, they are very scanty.

(v) Usually, roots are without a root cap.

(vi) In a few plants like *Ludwigia adscendens, Jussiaea* (pens) floating roots are present in addition to normal roots.

Stem:

(i) The stem of immersed plants like *Hydrilla verticillata* is thin, elongated, and spongy.

(ii) The stem of free-floating hydrophytes like *Azolla pinnata* is long, thin, floats on water, or is stoloniferous in *Eichhornia crassipes*.

(iii) The stems of a few plants are rhizomatous as in *Nymphaea pubescens, Nelumbo nucifera*.

(iv) Runners, stolons, offsets, etc., are also present in certain plants and they help in vegetative reproduction.

Leaves:

(i) Leaves of immersed hydrophytic plants like *Vallisneria spiralis* are thin, filiform, and ribbon-shaped or of a dissected type, e.g., *Ceratophyllum demersum*.

(ii) Floating leaves like those of *Nelumbo sp.* or *Nymphaea sp.* are large-sized, flat, smooth, and the upper surface is covered with a waxy coating.

(iii) Floating leaves are with long petioles; the petiole is delicate and sometimes with mucilage.

(iv) Petiole of some plants like *Trapa patens*, and *Eichhornia crassipes, Monochoria hastata* are swollen.

(v) Leaves of immersed hydrophytic plants are slightly transparent.

Anatomical adaptation

Root

(i) Usually, roots are devoid of cuticle or with a thin cuticle.

(ii) Epidermis is unilayered and is constituted of thin-walled parenchyma.

(iii) Cortex is well developed, constituted of thin-walled parenchymatous cells. A large portion of the cortex has aerenchymatous air cavities. Air cavities help in gaseous exchange and also give buoyancy to the plant.

(iv) Vascular tissues are not well developed and usually xylem does not contain vessels.

(v) Usually, mechanical tissues are absent, but the sclerenchymatous pith is present in *Typha domingensis*.

Stem

(i) Stems are without cuticle and if present then the cuticle is very thin.

(ii) Epidermis is unilayered and constituted of thin-walled parenchymatous cells.

(iii) A well-developed epidermis is present in rhizomatous stem in the case of *Nymphaea* sp. and

Nelumbo sp.

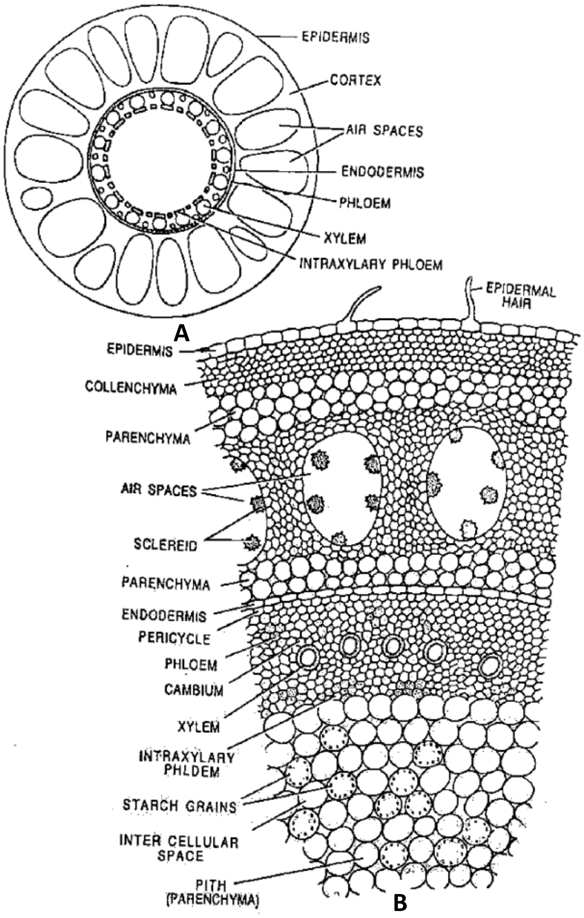
(iv) Stems of immersed plants do not have hypodermis. But in floating hydrophytic plants, the hypodermis of the stem is made up of thin-walled parenchyma or collenchyma cells (Fig. 31).

(v) Cortex is well developed. It is made up of thin-walled parenchymatous cells.

(vi) A large number of air cavities are present in the cortex. Cortical cells contain chloroplasts, so they help in photosynthesis (Fig. 31).

(vii) Vascular bundles are without bundle sheath. Conducting tissues are composed of thin-walled cells.

(viii) Mechanical tissues are absent.



Anatomy of hydrophytic stem. ***Trapa bispinosa*** **(dicot.) A, diagrammatic; B, detail—T.S. showing epidermis, cortex, vascular cylinder and large pith. Cortex consists of collenchyma and parenchyma; big air spaces in the cortical region. Calcium oxalate sclereids present in the cortex. The endodermis, pericycle, phloem, cambium, xylem are present. Intraxylary phloem patches present around the pith. Large intercellular spaces among pith cells.**

Leaves

(i) Cuticle absent in the leaves of immersed hydrophytic plants.
(ii) Floating hydrophytic leaves are with scanty cuticle only on upper epidermis.
(iii) Epidermis is unilayered and is constituted of thin-walled parenchymatous cells and with a large amount of chloroplast.
(iv) Stomata are absent in immersed hydrophytic leaves, e.g., *Anacharis* sp., *Potamogeton* sp.
(v) Stomata are restricted only to the upper surface of floating leaves. Stomata are present on both surfaces of leaves which are present above the water surface.
(vi) Mesophyll tissue is not divisible in immersed hydrophytic leaves. In certain cases like *Potamogeton* sp., mesophyll tissue is unilayered.
(vii) Mesophyll tissue is divisible into spongy and palisade parenchyma in the floating leaves. Air cavities are also present in mesophyll tissue.
(viii) Vascular tissues are ill developed. In a few cases like *Anacharis* sp., xylem and phloem tissues are not well distinguishable.
(ix) Xylem and phloem are clearly visible in the leaves of floating plants.
(x) Mechanical tissues are absent.
(xi) Leaf-like characteristic features are present in the leaf petioles of floating hydrophytes.

Physiological adaptation

(i) Certain hydrophytic plants perform anaerobic respiration due to the paucity of oxygen in their habitats.
(ii) Low demand for oxygen can be seen in certain hydrophytic plants.
(iii) Gaseous exchange is performed due to the presence of air cavities.

Summary

From the study, it can be concluded that the dermal tissue system of plants—such as epidermis, cuticle, stomata, hairs, bulliform cells, hydathodes, etc.—all act as protective tissues. The adaptive system of plants is ensured by their own adaptation to the environmental conditions.

Questions

1. Write notes on (a) Epidermis and (b) Cuticle.
2. Draw and describe different types of stomata found in plant groups.
3. Describe different types of stomatal complex in monocotyledons according to Stebbins and Khush (1961). Describe the ontogenetic classification of stomata according to Pant (1965).
4. Write down the adaptive features present in xerophytic plants.

5. Write down the adaptive morphological and anatomical features in hydrophytic plants.

Answers

1. See article no. 4.2.1 & 4.2.2
2. See article no. 4.2.4
3. See article no. 4.2.5 & 4.2.6
4. See article no. 4.3.2
5. See article no. 4.3.3

Unit 7: Flower

7.0 Objective

From this unit learners will gather knowledge related to the structural organization of flower, specially anther and pollen structure, forms of anther lobes, attachment of anther to the filament.

Learners will be able to discuss about the anther dehiscence mechanism.

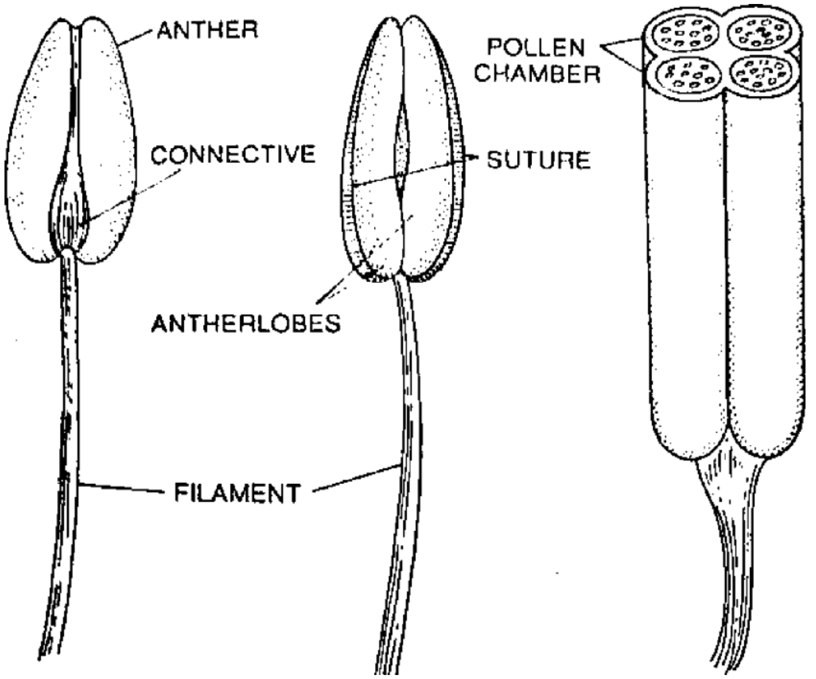
Learners can describe the ovule structure and its types.

5.1 Introduction

The flower is highly specialized reproductive shoot. Each typical flower consists of four distinct types of members arranged in four separate but closely set whorls, one above the other, on the top of a long or short stalk. The lower two whorls are called accessory whorls and the upper two essential or reproductive whorls as these two are directly concerned in reproduction. The essential whorls consists of two kinds of sporophylls—microsporophylls or stamens and megasporophylls or carpels. Both kinds of sporophylls may be present in a flower i.e., hermaphrodite flower or only one i.e.,unisexual flower may be seen in some plants.

Structure of anthers and pollens

The androecium is the first essential and third member of the floral whorl. The androecium is the male reproductive component of a flower, and its individual members are the stamens, which are the microsporophylls (Fig. 32a, b). The stamen or microsporophyll consists of three parts: filament, anther, and connective. The filament is the slender stalk of the stamen, and the anther is the expanded head borne by the filament at its tip. Each anther usually consists of two lobes connected together by a sort of midrib known as the connective. Each anther lobe contains two pollen-sacs.



a.Dorsalview b.Ventralview c.T.S.ofanther

Fig.32:a.Stamen,a–dorsalview;b–ventralview;c–T.S.ofanther

or microsporangia, thus there are four chambers in each anther. But in many cases there are only two and sometimes even only one, e.g., Hibiscus rosa-sinensis, Sida cordifolia, etc. Within each pollen-sac there is a fine, powdery or granular mass of cells, called the pollen grains or microspores. Pollen grains are produced in large quantities in the pollen-sacs.

Each stamen develops as a small papillate outgrowth of meristematic tissue from the growing tip of the floral primordium. It grows actively and soon gets differentiated into an apical broader portion, the anther, and the lower slender part, the filament.

The cross section of a very young anther consists of a homogeneous mass of meristematic cells surrounded by an epidermal layer. Further growth of the anther makes it four-lobed (Fig. 32c).

The number of stamens varies from one to many. Depending on the number of stamens, the flowers are grouped as:

(a) Monandrous: Flowers are with one stamen, e.g., Curcuma longa, Zingiber officinale.
(b) Diandrous: Flowers are with two stamens, e.g., Adhatoda vasica.
(c) Triandrous: Flowers are with three stamens, e.g., Triticum aestivum, Cyperus rotundus.
(d) Tetrandrous: Flowers are with four stamens, e.g., Ocimum tenuiflorum, Leonurus sibiricus.
(e) Pentandrous: Flowers are with five stamens, e.g., Solanum nigrum, S. melongena.
(f) Hexandrous: Flowers are with six stamens, e.g., Oryza sativa, Bambusa tulda.
(g) Polyandrous: Flowers are with numerous stamens, e.g., Rosa centifolia, Ricinus communis, Acacia nilotica, etc.

Attachment of anther to the filament

The anther becomes attached to the filament in various ways. These are:

Adnate: The filament or connective remains attached at the back of the anther throughout the whole length, e.g., Magnolia sp.

Innate or basifixed: Here the filament apex becomes firmly attached to the base of the anther, e.g., Argemone sp., Solanum sp.

Dorsifixed: The apex of the filament becomes firmly attached to the back of the anther, e.g., Sesbania sp., Passiflora sp., Polianthes tuberosa.

Versatile: Filament attached at a point near the middle of the back of the connective in such a way that anther moves freely in air, e.g., Oryza sativa, Gloriosa superba, etc.

5.3.3 Forms of anther lobes

Generally, anthers are bilobed and quadrilocular, but rarely the anthers are unilocular, e.g., Hibiscus rosa-sinensis. The anther may be of different shapes as follows:

- **Linear:** Long and narrow, e.g., Acalypha indica.
- **Rounded or oval:** Anthers are rounded, e.g., Mercurialis annua.
- **Appendiculate:** Lobes provided with appendages, e.g., Erica cinerea.
- **Reniform:** Anthers are kidney-shaped, e.g., Hibiscus rosa-sinensis.
- **Sagitate:** Anthers are arrow-shaped, e.g., Catharanthus roseus.
- **Sinuous:** Here, anther lobes are convoluted, forming an ‘S’-shaped structure, e.g., Cucurbita maxima.
- **Filamentous:** Lobes of anther are thread-like, e.g., Zosteras sp.

Dehiscence of anthers

The pollen grains inside the mature anther exert some pressure on the outer wall, thereby the anther lobes burst open and the pollen grains are set free. Dehiscence of anthers may be of different types as follows:

- **Transverse:** The anther splits up transversely, e.g., Hibiscus rosa-sinensis.
- **Apicular porous:** Pollen are discharged through apical pores, e.g., Solanum tuberosum, cassia sp.
- **Valvular:** Pollen are discharged through a trap-door-like valve formed on the anther wall, e.g., Berberis vulgaris, members of Lauraceae such as Cinnamomum, Litsea, etc.
- **Longitudinal:** The anther lobes burst lengthwise along the line of suture from base to apex, e.g., Datura sp., Vitis vinifera.

Connective Types

Connective is a tissue which connects the two parallel anther lobes. It is of different types.

- **Discrete:** The connective is very small or wanting; here the anther lobes remain very close to each other, e.g., Poinsettia pulcherrima.
- **Divaricate:** The connective develops in such a way that the anther lobes get separated from each other, e.g., Justicia gendarusa, Lindenbergia indica.
- **Distractile:** Here, the connective is long-stalked like a body which separates the two anther lobes, of which one is sterile and the other one is fertile, e.g., Salvia plebeja.

Structure of Pollen Grains

The pollen grains or microspores are the male reproductive bodies of a flower and are contained in the pollen sac or microsporangia. They are very minute in size, and

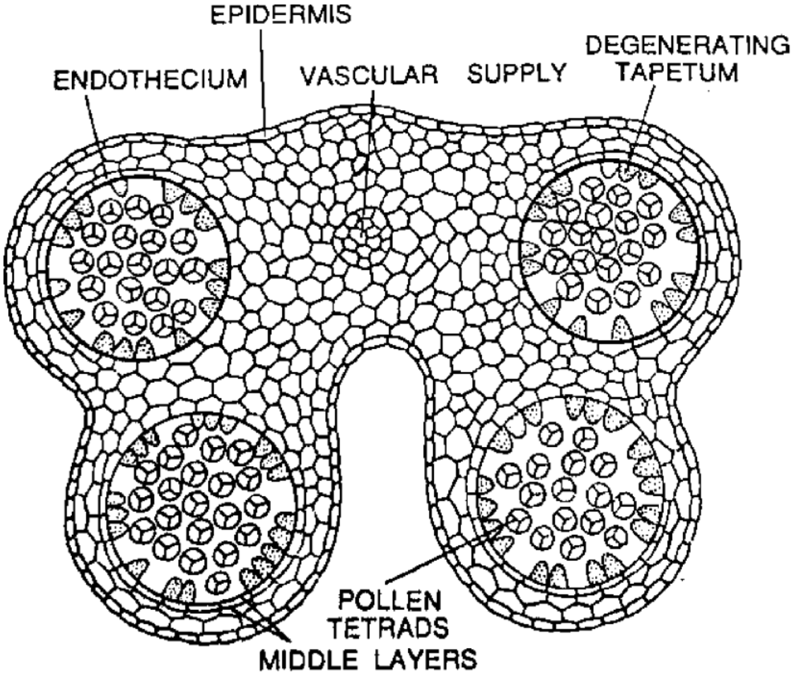
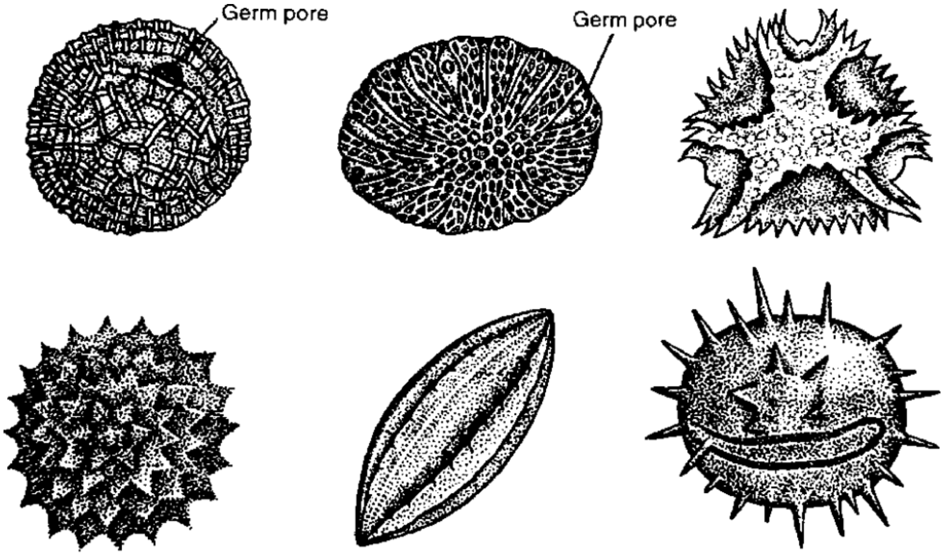


Fig.33: **Anther. T.S. of an anther showing tetrads of pollen grains.**

are like particles of dust. There are the first cell of the male gametophyte, which contains only one haploid nucleus. The word pollen grains are generally applied in case of gymnosperm and angiosperm group of plants. Pollen grains which develop with the microsporophyll of the gymnospermic group of plants and within the anther of the angiospermic group of plants are termed as pollen grains (Fig. 33).

Pollen grains are of various shapes such as polyhedral, e.g., Sonchus palustris; cubical in Basella alba; trigonal in members of Onagraceae; cylindrical in Tradescantia spathacea, etc. Walls of pollen grains are multilayered, thick, and sculptured.

The pollen grains have two walls — outer exine; the exine is further differentiated into two sub-layers, i.e., outer sexine or ektexine and inner nexine or endexine, and the inner intine. The exine is cutinised and tough with different ornamentations. It may be warty, spiny, etc. It can protect the pollen from external injury. The intine is very thin, elastic and delicate. Structure of some pollen grains are (Fig. 34) illustrated with different sculptures.



Different pollen grains showing various types of sculpturing

Usually, the mature pollens remain separated from one another. In plants like *Typha angustifolia*, pollens do not get separated from one another, i.e., compound pollen grain. In orchids (Fig. 35a) and in *Calotropis procera* (Fig. 35b); all the pollen grains within each pollen sac remain united forming the structure known as pollinium.

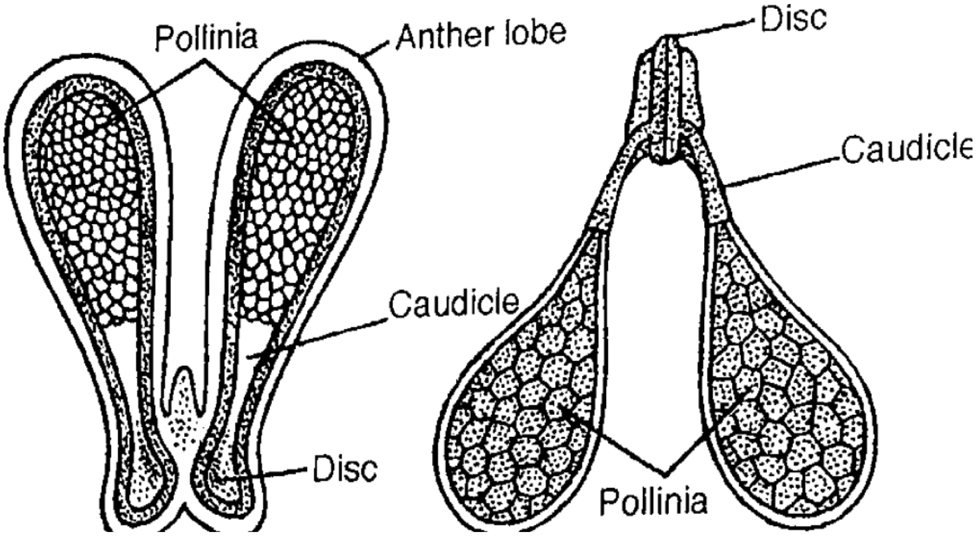
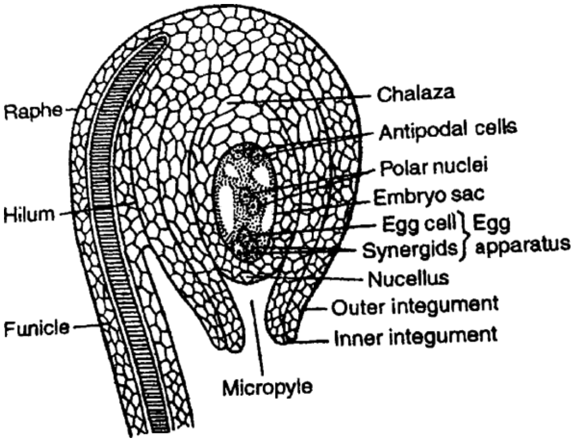


Fig.35: Pollen grains and Pollinia:a. Pollinia of *Orchis* sp. b.Pollinia of *Calotropis procera*

Structure of ovule

An ovule may be defined as an unfertilized, integumented, indehiscent megasporangium. It develops from the base of the inner surface of the ovary.

The ovule is small, generally of oval structure, and consists mainly of a central body of tissue, the nucellus and one or two integuments. Each ovule is attached in the placenta by a small stalk called the funiculus. The place of attachment of the stalk with the main body of the ovule is called the hilum. In an inverted ovule, the funiculus, fused with the main body of



Longitudinal section of a typical ovule of angiosperm (anatropous type)

the ovule, forming a short ridge, known as the raphe (Fig. 36). The upper end of the raphe, which is the junction of the integuments and the nucellus, is called the chalaza.
The nucellus makes the main body of the ovule, which is made up of parenchyma tissue. Nucellus is the megasporangium proper and is surrounded by two coats, the integuments. A small opening left at the apex of the integuments is called the micropyle. When there are two integuments, then the inner integument is formed first, followed by the formation of the outer integument. A large oval cell lying embedded in the nucellus towards the micropylar end is the embryo sac. This makes the most important part of the mature ovule. It is the embryo sac which later bears the embryo.

Types of ovules

On the basis of the relative position of the micropyle, chalaza, and funiculus of the mature ovules as found in angiosperms, there are six types, and these are described below (Fig. 37):

(a) **Orthotropous or straight or atropous:** In this type the ovule is erect or straight so that the funiculus, chalaza, and micropyle lie in one and the same vertical line, as in *Polygonum*, *Rumex*, *Peperomia pellucida*, etc., and *Piper nigrum*, *Piper betle*, etc.

(b) **Anatropous or Inverted:** In this type the ovule bends along the funiculus so that the micropyle lies close to the hilum. The chalaza lies at the other end. This is the commonest type of ovule found in both dicots and monocots, e.g., in Moraceae, *Pisum sativum*.

(c) **Amphitropous or Transverse:** The ovule is placed transversely at a right angle to the stalk or funiculus, as found in *Lemma*, *Argemone mexicana*, etc.

(d) **Hemitropous or Hemianatropous:** In this type the body of the ovule is straight but twisted in such a way that it is placed transversely at a right angle, so that the chalaza–micropyle line is at a right angle to the funiculus. It is found in *Ranunculus*.

(e) **Campylotropous or Curved:** In this type the transverse ovule is bent around like a horseshoe so that the micropyle and the chalaza do not lie in the same straight line, as in *Capparis*, *Chenopodium album*, *Cicer arietinum* and *Mirabilis jalapa*, etc.

(f) **Circinotropous:** In this type the nucellus and the axis remain in the same line in the beginning, but due to rapid growth on one side, the ovule gets inverted. This curvature continues and thus the ovule turns completely, and once again the micropyle faces upwards. This type is found in *Opuntia* and *Plumbago*, *Batis maritima*, etc.

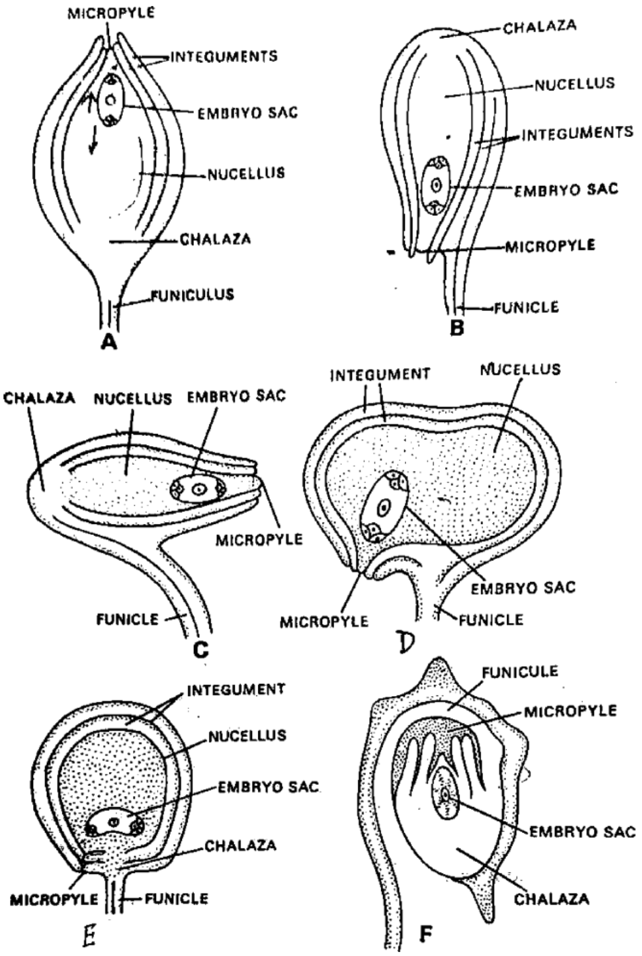


Fig. 37: Different types of the ovule in longitudinal section. A. orthotropous; B. anatropous; C. amphitropous; D. hemianatropous; E. campylotropous; F. circinotropous.

Summary

Structural organization of flower revealed the nature of reproductive parts, specially the nature of sporophylls i.e. both the microsporophylls and megasporophylls. Knowledge regarding the organization of stamens and the grouping of flowers on the basis of number of stamens can be achieved through the detailed study. Mode of attachment of anther to the filament, anther forms, its dehiscence pattern, connective type, structures of pollen grains, ovules and ovular types can easily be understood.

Questions

1. With suitable illustration describe the structure of an anther.

2. Write notes on flower group depending on the number of stamens and the attachment of anther to the filament with examples.
3. Write notes on forms of anther lobes and dehiscence of anther with examples.
4. Give a detail outline of the structure and types of ovules with examples.

Answers

1. See article no.7.2
2. See article no.7.2.1& 7.2.2
3. See article no.7.2.3& 7.2.4
4. Seearticleno.7.4 & 7.5

Unit 8: Embryo Sac

8.0 Objective

From this unit learners will gather knowledge related to the different types of embryo sac.

Learners will be able to describe about the organization and ultra structure of mature embryo sac.

8.1 Introduction

The megaspore (n) makes the beginning of the megagametophyte or female gametophyte generation. The nucleus of the megaspore divides and develops into the female gametophyte or the embryo sac. The female gametophyte of angiosperms is very much reduced and totally dependent upon the tissue of the sporophyte for its nutrition. The functional megaspore becomes enlarged at the expense of tapetum and the nucellus and thus forms the female gametophyte *i.e.*, the embryo sac.

Types of Embryo sacs

The megaspore (n) makes the beginning of the megagametophyte or female gametophyte generation. The nucleus of the megaspore divides and develops into the female gametophyte or the embryo sac. The female gametophyte of angiosperms is very much reduced and totally dependent upon the tissue of the sporophyte for its nutrition. The functional megaspore becomes enlarged at the expense of tapetum and the nucellus and thus forms the female gametophyte, i.e., the embryo sac.

Depending on the number of megaspores taking part in the development of the embryo sacs of angiosperms, the embryo sac may be classified into three main categories as monosporic, bisporic and tetrasporic.
In the monosporic type, only one of the four megaspores takes part in the development of the female gametophyte or embryo sac. In the bisporic type, two megaspore nuclei take part in the development of the female gametophyte or embryo sac. However, in the tetrasporic type, all the four megaspore nuclei take part in the development of the female gametophyte or embryo sac.

They have been further subdivided into the following types (Fig. 38) on the basis of the number of nuclear divisions that take place between the time of megaspore formation and the time of differentiation of the egg and the total number of nuclei present in the gametophyte at the time when such organization takes place.

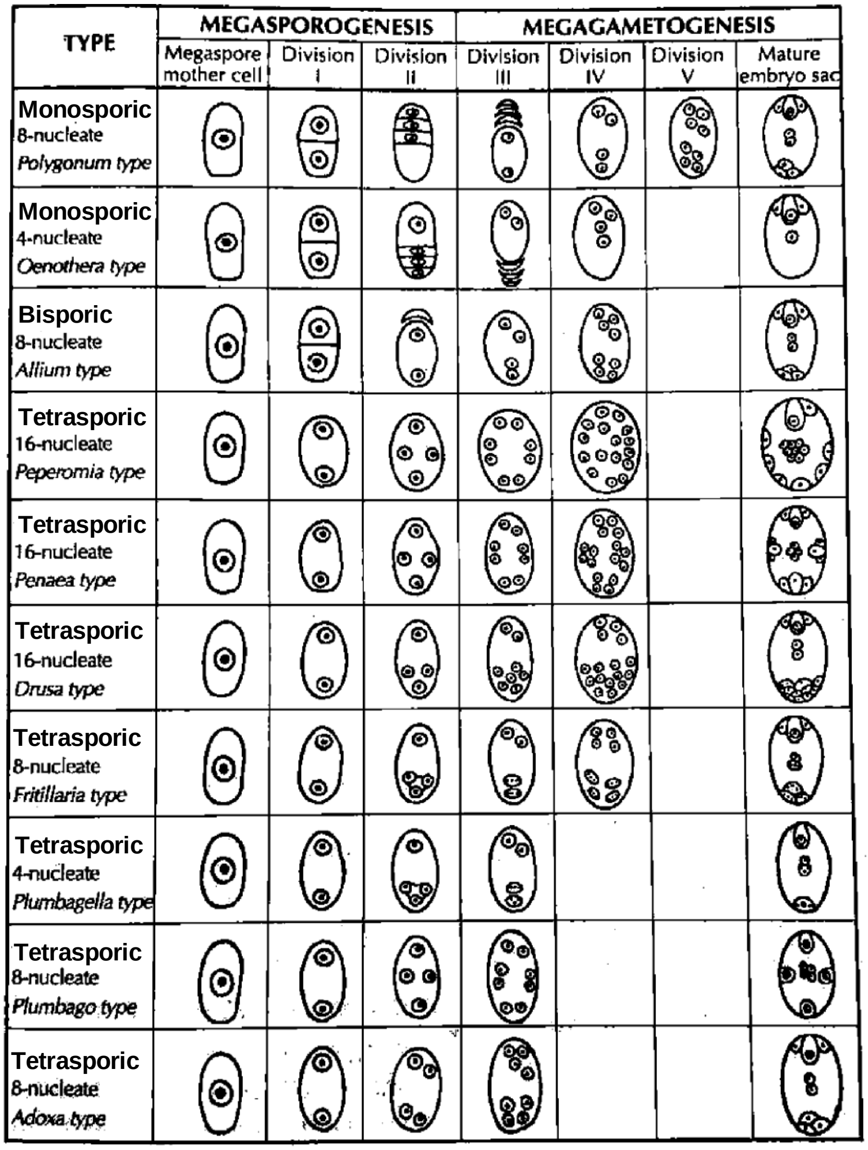
Monosporic type:

Where, out of four megaspores, only one remains functional and forms the embryo sac, it is said to be monosporic. The female gametophytes or embryo sacs of this type may be 8-nucleate or 4-nucleate.

4 **Polygonum or Normal type**

This Polygonum type of embryo sac is the most common and generally known as the normal type. The Polygonum type of embryo sac was first reported in *Polygonum divaricatum* by Strasburger (1879).

In the development of the 8-nucleate embryo sac, the nucleus of the functional megaspore divides to form two nuclei: the primary micropylar and the primary chalazal nuclei. These nuclei again divide so that the number is increased to four. Each of these nuclei divides again so that altogether eight nuclei are formed in the embryo sac, four at each end. The female gametophyte, i.e., the embryo sac, increases in size. Now one nucleus from each pole passes inwards and the two polar nuclei fuse together in the middle of the embryo sac forming the secondary nucleus (2n). The remaining three nuclei at the micropylar end, each surrounded by a very thin wall, form the egg



Development of different types of embryo sac in angiosperms (*after* Maheshwari)
[Micropyle above in all illustrations]

The other three nuclei at the opposite or chalazal end, lying in a group, often surrounded by very thin walls, form the antipodal cells.

2. **Oenothera type**
   Another variation of the monosporic type of embryo sac is known as the Oenothera type and has been reported only in the family Onagraceae. In this type the megaspore nucleus divides twice and thus produces four nuclei at the micropylar end. These nuclei give rise to a normal egg apparatus and a single polar nucleus. The second polar nucleus and the

antipodal nuclei are absent. This is found in *Oenothera* and other members of Onagraceae.

Bisporic type:

The type of embryo sac where two megaspore nuclei take part in the development of the embryo sac is known as the bisporic type.

3. **Allium type**
   This type of embryo sac arises from one of the two dyad cells formed after meiosis I. Since there is no wall formation at the end of meiosis II and both the megaspore nuclei formed in the functional dyad cell take part in the development of the embryo sac, only two further divisions of these nuclei give rise to the 8-nucleate stage.
4. **Endymion type**
   This type of embryo sac was reported for the first time in *Endymion hispanicus*, now known as *Hyacinthoides hispanica* (Hyacinthaceae). In this type, after the formation of the dyad, the lower cell may disintegrate or its nucleus may divide once or twice, producing 4 nuclei. The 8-nucleate embryo sac is formed by the nuclear divisions of the upper cell of the dyad.

Tetrasporic type:

The type of embryo sac where all four megaspore nuclei take part in the development of the embryo sac is known as the tetrasporic type. In several cases, 16 nuclei are formed as a result of two divisions after megasporogenesis.

5. **Peperomia type**
   Here each of the 4 megaspore nuclei divides twice, forming 16 nuclei which are uniformly distributed toward the periphery of the embryo sac. Two nuclei at the micropylar end form an egg and a synergid; 8 nuclei are fused to form the secondary nucleus, and the remaining 6 nuclei are cut off at the periphery of the embryo sac. This type is seen in *Peperomia* of Piperaceae.
6. **Penaea type**
   In this type, 16 nuclei lie in four distinct quarters which are arranged crosswise—one at each end of the embryo sac and two at the lateral sides. Later on, three nuclei of each quarter become cut off as cells, while the fourth one remains free and moves toward the centre. Thus, there are four triads and four polar nuclei. Here, the egg cell of the micropylar triad alone is functional.Such embryo sacs have been found in many members of Malpighiaceae.

7. **Drusa type**
   In this type, a sixteen-nucleate embryo sac was recorded in *Drusa oppositifolia* (family Umbelliferae). Here, when the meiotic divisions are over, three of the megaspore nuclei pass down to the basal end of the embryo sac and only one remains at the micropylar end. This is followed by two successive divisions, forming four micropylar nuclei and twelve antipodal nuclei. The four micropylar nuclei give rise to the egg apparatus and the upper polar nucleus, and the twelve chalazal nuclei form a lower polar nucleus and eleven

antipodal cells. This type of embryo sac has been recorded in *Mallotus*, *Rubia*, *Ulmus*, etc.

8. **Chrysanthemum cinerarifolium type**
   Martinoli (1939) has described a peculiar mode of development in this plant. In this type, four megaspore nuclei show a 1 + 2 + 1 arrangement, i.e., one nucleus lies at each pole and two in the centre. The two nuclei in the centre remain quite close to each other but do not fuse together. Now the megaspore nucleus at the micropylar end divides twice forming four nuclei, but there is no regularity in the division of the nucleus at the chalazal end. Thus, the embryo sac may have six, nine, or ten nuclei.
   Sometimes, the two central nuclei out of the four megaspore nuclei are fused together forming a single diploid (2n) nucleus; the next division produces six nuclei, one haploid (n) pair at the micropylar end, one haploid pair at the chalazal end, and one diploid pair in the centre. The next division of these six nuclei produces three groups of four nuclei each. At the micropylar end, the three nuclei make the egg apparatus, and one migrates in the centre forming the upper haploid polar nucleus. The four haploid antipodal cells are formed at the chalazal end. One of the diploid nuclei of the central quarter behaves as the lower polar nucleus and the remaining three organize as additional antipodal cells. Thus, there are twelve nuclei in the embryo sac. Sometimes less than twelve nuclei (i.e., ten or seven) are developed because of the failure of certain divisions.
9. **Fritillaria type**
   In this type, out of four nuclei formed, one nucleus remains toward the micropyle, and the rest three at the chalazal end. The chalazal nuclei fuse together and form a 2n nucleus. Both the cells thus undergo one mitotic division and again form a tetrasporic stage. Out of four nuclei, two remain at each pole. All the nuclei then undergo mitotic division and again form a tetrasporic stage. Out of four nuclei, two remain at each pole. All the nuclei then undergo mitotic division and form eight nuclei. Out of four haploid nuclei at the micropyle, one egg and two synergids are formed, those remain at the micropyle end; three triploid nuclei are formed at the chalazal end and one from each pole remains at the centre (one haploid and the other one triploid). This type is found in *Fritillaria*, *Tulipa* and some other members of Liliaceae.
10. **Plumbagella type**
    It is like the Fritillaria type, which forms the 1st and 2nd tetrasporic stage with two haploid nuclei at the micropyle and two triploid nuclei at the chalazal end of the embryo sac. Later on, these nuclei are distributed in such a way that the egg is at the micropyle, one triploid plus one haploid nucleus at the centre. It is found in *Plumbagella* of Plumbaginaceae.
11. **Plumbago type**
    This type of embryo sac development has been reported in *Plumbago auriculata capensis* P. (Haupt, 1934). Here the four megaspore nuclei arrange crosswise and divide once to form eight nuclei in four pairs. One nucleus of the micropylar pair is now cut off to form the lenticular egg cell, and one nucleus from each of the four pairs approaches each other in the centre and fuses to form a tetraploid secondary nucleus. The remaining three nuclei degenerate.
12. **Adoxa type**
    This type of embryo sac development was described for the first time by Jonsson (1879) in *Adoxa moschatellina*. In this type, the four megaspore nuclei divide to form eight

nuclei which form a normal type of 8-nucleate embryo sac, i.e., a normal egg apparatus, three antipodal cells and two polar nuclei. This type of embryo sac is a regular feature in *Adoxa* and *Sambucus*.

Organization and Ultrastructure of Mature Embryo Sac

In the majority of angiosperms, the eventual organization of the embryo sac shows a uniform pattern, whereas the origin of the mature embryo sac may differ. The Polygonum, Allium, Fritillaria and Adoxa types have similar appearance at the time of fertilization (i.e., a three-celled egg apparatus, three antipodal cells, and two polar nuclei). However, in a few genera such as *Peperomia*, *Plumbago*, *Plumbagella*, etc., the basic plan of the embryo sac is different.

The Egg Apparatus:

Typically, the egg apparatus consists of an egg and two synergids. Usually, the synergids are ephemeral structures that degenerate and disappear soon after fertilization or sometimes even before it. As a rule, each synergid is notched and possesses a prominent hook (Fig. 39a). The nucleus lies in or just below the hook and the lower part of the cell contains a large vacuole. In the egg cell, the nucleus and most of the cytoplasm are located in the lower part of the cell while the vacuole occupies the upper part (Fig. 39b).

Antipodal Cells:

The antipodals are usually short-lived. However, they frequently show a considerable increase in size or number. An increase in the number of antipodal cells and in the number of nuclei per antipodal cell is frequently found in the Compositae. The antipodal cells of some members of Ranunculaceae become greatly enlarged and glandular in appearance.

Polar Nuclei:

The central portion of the embryo sac contains polar nuclei that eventually give rise to the endosperm, and are therefore known as the endosperm mother cell. Usually, the two nuclei coming from two different poles are similar in appearance, but sometimes the micropylar polar nucleus is larger (Fig. 39c). The fusion of the polar nuclei may occur either before, during, or sometimes after the entry of the pollen tube into the embryo sac.

Ultrastructural studies on the mature embryo sac of natural tetraploid *Trifolium pratense* revealed that the mature embryo sac of this plant contains an egg cell with two synergids at the micropylar end and a central cell with two polar nuclei. The mature embryo sac of *Trifolium pratense* is monosporic, 8-nucleate and is of the Polygonum type. Thus, the mature embryo sac contains an egg apparatus composed of an egg cell and two synergids at the micropylar end, a central cell with two polar nuclei, and three antipodal cells at the chalazal end. The large bases of the synergid cells partially cover the egg cell, and the polar nuclei remain very close to the egg apparatus (Fig. 39a). A longitudinal section of the mature embryo sac shows the presence of a large, ovate egg cell. Its width is broader at the chalazal end and gets narrower toward the micropylar end. It is attached to the embryo sac slightly above the base of the two synergids. The nucleus and most of the cytoplasm are located at the chalazal end of the cell, and the egg nucleus contains a single large nucleolus. The egg cytoplasm contains only a few organelles. Ribosomes are more concentrated in the micropylar region of the egg cell cytoplasm; they are either attached to the endoplasmic reticulum or are free in the ground cytoplasm throughout the egg cell. Mitochondria are numerous and are more concentrated in the micropylar region. The egg cell is surrounded by a partial cell wall.

The two synergids partially surround the egg. Each synergid has a common wall either with the egg or with the other sister synergid. The micropylar end of both cells is occupied by the complex filiform apparatus (FA). The FA consists of an extensive labyrinth of wall projections extending deep into the synergid cytoplasm. The synergid cytoplasm shows a complex organization and is rich in organelles, with a large vacuole and several small vacuoles located throughout the cytoplasm at the chalazal end of the cell (Fig. 39b).

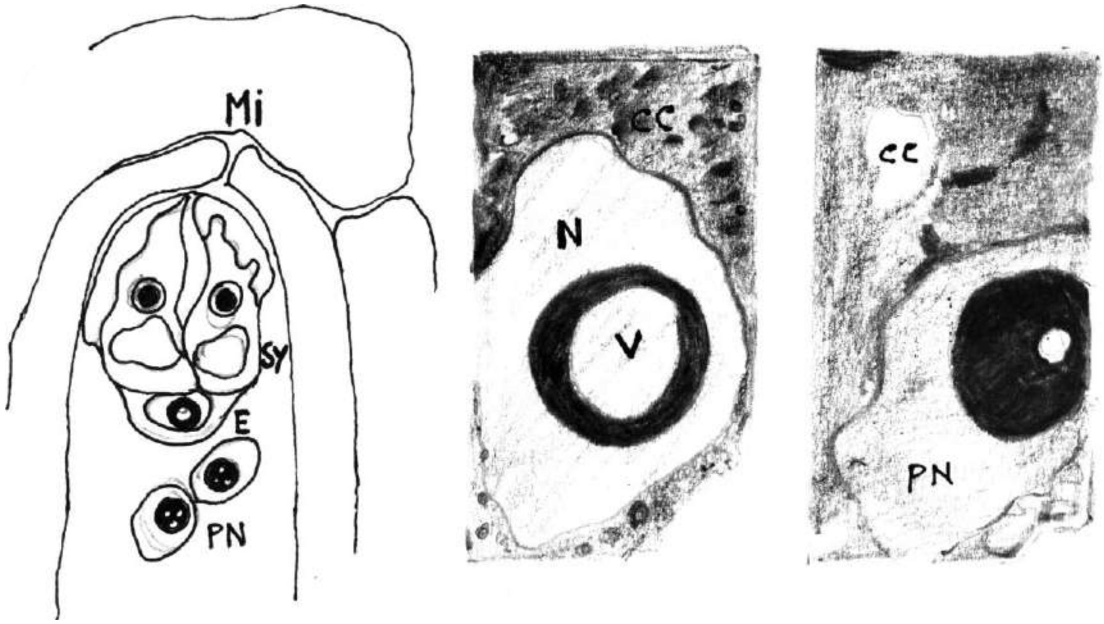


Fig. 39a: Longitudinal section of the micropylar end of the mature embryo sac showing the egg cell (E), two synergids (SY) and two polar nuclei (PN). **b:** Electron micrograph showing the egg cell nucleus (N) and the nucleolus (NU) containing a big central vacuole (V). **c:** Electron micrographs showing a longitudinal section of the central cell (CC).

Summary

In this unit the knowledge regarding the types of embryo sacs and organization as well as ultra structure of mature embryo sac can be achieved through the detailed study.

Questions

5. Define embryo sac.
6. Give detailed outline of a tetrasporic embryo sac and mention their types.

Answers

5. See article no.8.1
6. See article no.8.2

Unit 9: Pollination

9.0 Objective

From this unit learners can easily understood about the pollination mechanism.

Learners will be able to describe about the adaptations for self and cross pollination.

9.1 Introduction

Pollination is a vital biological process that enables plants to reproduce by transferring pollen from the male part of a plant (anther) to the female part (stigma) of the same or another plant. This process is essential for the production of seeds and fruits, which contain the genetic material necessary for the growth of new plants.

Pollination mechanisms and adaptations

Pollination is of two types as (i) self pollination and (ii) cross pollination.

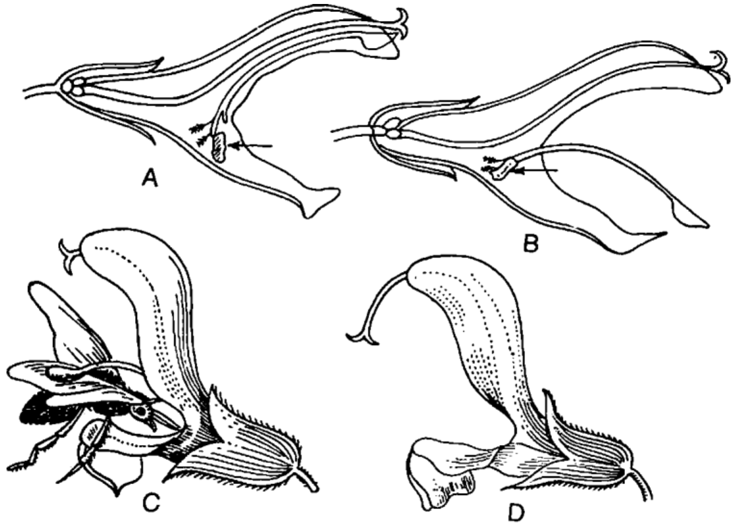
(i) **Self pollination** or homogamy or autogamy: When the pollen grains are transferred from an anther to the stigma of the same flower, it is known as self pollination, e.g., *Commelina benghalensis*, *Argemone mexicana*, *Mirabilis jalapa*, etc. On the other hand, when pollen grains are transferred from the anther of a male or bisexual flower to the stigma of a female or another bisexual flower occurring in the same plant, it is termed as geitonogamy.

(ii) **Cross-pollination** or allogamy: When the pollen grains are transferred from an anther of one flower to the stigma of another flower borne by a different plant of the same or different species. All unisexual flowers are generally cross-pollinated. Cross-pollination that takes place between two different plants of the same species is termed as xenogamy, and between two different species is known as hybridism.

Pollination mechanism

Mechanisms of pollination are different. However, in the case of a few common plants these are as follows:

(i) In *Salvia* sp. (Labiatae) cross-pollination is brought about by special, elaborate development of morphological structures in the androecium. The stamens, numbering two, are provided with a long connective; the anterior end of the connective forms a knob at the end of an arm—thus a lever arrangement with spring action has been elaborated (Fig. 40). The lower lip of *Salvia* forms a landing stage for insects (e.g., bees). Honey is secreted on the lower side of the hypogynous disc. The single anther lobe of the stamen is concealed in the head like upper lip. A bee in search of nectar sits on the lower tip, then in attempting to get nectar it touches the knob of the sterile anther, as a result of which the upper fertile anther lobe strikes on the back of the bee. The back of the bee is thus dusted with pollen. The style with forked stigmas forms a bent structure. As the bee with the pollen powder on its back enters another mature flower, the pollen powder is caught by the forked recurved stigmas from the back of the bee. The flowers of Salvia are highly protandrous and have a corolla arrangement of 2/3 type, i.e., upper lip of two lobes and lower of three lobes.



Pollination mechanism in *Salvia* sp.

(ii) In Lathyrus odoratus (Papilionaceae) the construction of the flower itself is an adaptation for cross-pollination by insects, commonly by bees. The standard is the flag apparatus, and the wing petals, i.e., the carina, serve as the landing stage for insects. The flower is so constructed that the weight of the insect on the wing petals causes the carina to come down – as a result, the hidden stigma within the sheathing filament jerks out and consequently comes in contact with the pollen-dusted body of the insect.

(iii) In Calotropis sp. (Asclepiadaceae) there is a highly elaborated arrangement for cross-pollination by means of insects, e.g., bees. The corona-like appendages are associated with the secretion and storage of nectar in Calotropis. Here the pollen is not granular but aggregated into two waxy masses – the so-called pollinia – which are attached to each other by slender stalk-like processes known as translators, whose end is a notched, knob-like structure, the corpusculum. Stamens and pistils are adherent to form a gynostegium. The anthers are adherent on the lateral sides of the pentagular stigma (Fig. 41). There are small openings or slits between the adjacent cells of the anther. A bee or other insects in search of nectar

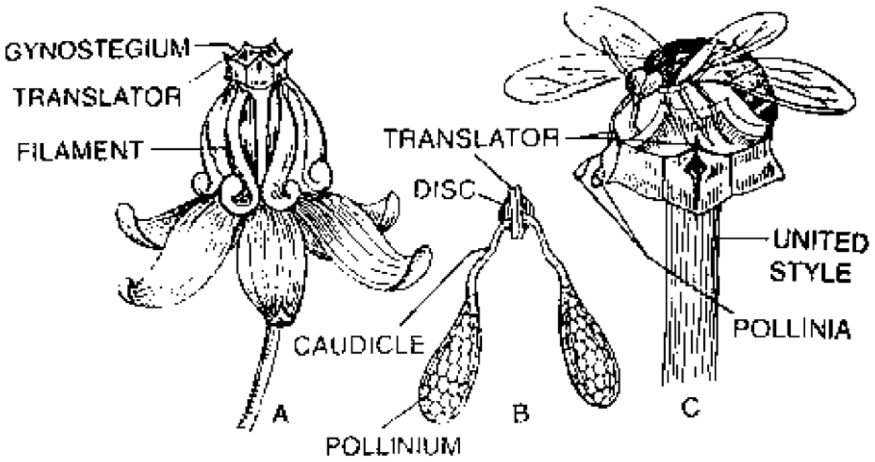
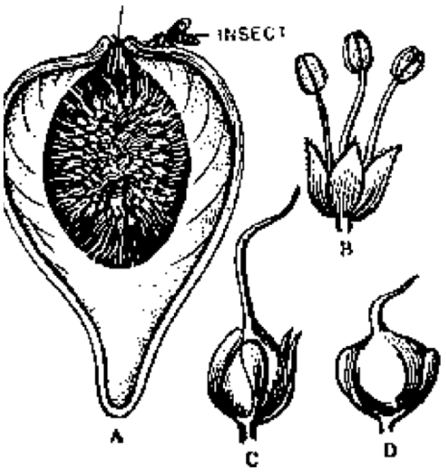


Fig.41: Pollination mechanism in *Calotropis* sp. A—Flower. B—A pair of pollinia. C—A bee removing a pair of pollinia from the gynostegium.

comes in contact with the notched corpusculum which comes out partially through the slits of anthers. The corpusculum is hygroscopic; it is caught by the leg of the insect. When the insect retires from the flower, it drags with it the whole pollinium attached to its leg, and on visiting another flower the pollinia are deposited on the adhesive stigma of the same. Thus, cross-pollination is easily brought about by insects.

(iv) In *Ficus* sp. (Moraceae), the flowers are adapted for cross-pollination by an insect, the gall wasp (*Blastophaga*). Here, the small flowers are almost enclosed by the receptacle of the hypanthodium, syconium (Fig. 42), but there exists a small opening (ostiole), closed by overlapping bracts, through which small insects, e.g., gall wasps



Pollination mechanism in *Ficus* sp. (fig) —L.S. of the hypanthodium showing the entry o gall wasp. B—Male flowers. C—Female flowers. D—Gall flowers.

enter. The hypanthodium contains three kinds of flowers – the male flowers and two kinds of female flowers – one with short styles known as gall flowers which are sterile and the others with long styles, which are fertile. Pollination is brought about by means of very small wasps, the so-called gall wasps (*Blastophaga*), which enter the hypanthodium through its small apical pore to lay their eggs in the ovaries of gall flowers. As the male flowers are present, the bodies of wasps are dusted with pollen. The wasps, on entering another hypanthodium, come in contact with the stigma of fertile female flowers, thus cross-pollination is effected.

(v) *Aristolochia indica* (Aristolochiaceae) flower is with a long perianth tube, swollen at the base (Fig. 43). The swollen part encloses the sex organs. The inner side of the tube is slippery and with deflected hairs. The flowers are protogynous, i.e., the gynoecium matures earlier than the anthers. Small insects are attracted by the foul odor and bright color of the flowers. The deflected hairs allow the entry of flies into the base of the perianth tube but prevent their escape. During its attempt to come out from the flower, it rubs against the stigma and thereby pollination is effected if the fly carries pollen from another flower. Later on, the hairs wither, enabling the fly to escape.

(vi) In *Vallisneria spiralis* (Hydrocharitaceae), the flowers are borne underwater. After maturation, the pistillate flowers are brought to the surface by their long stalk and form a cup-like depression. The male flowers get detached from the male plant and float on the surface of the water. If the female flowers get lodged into the depression, pollination occurs.

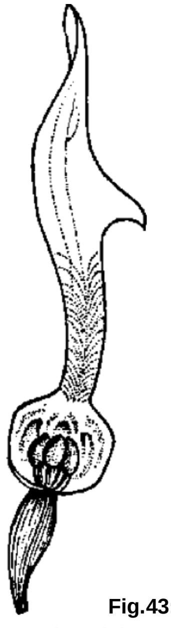
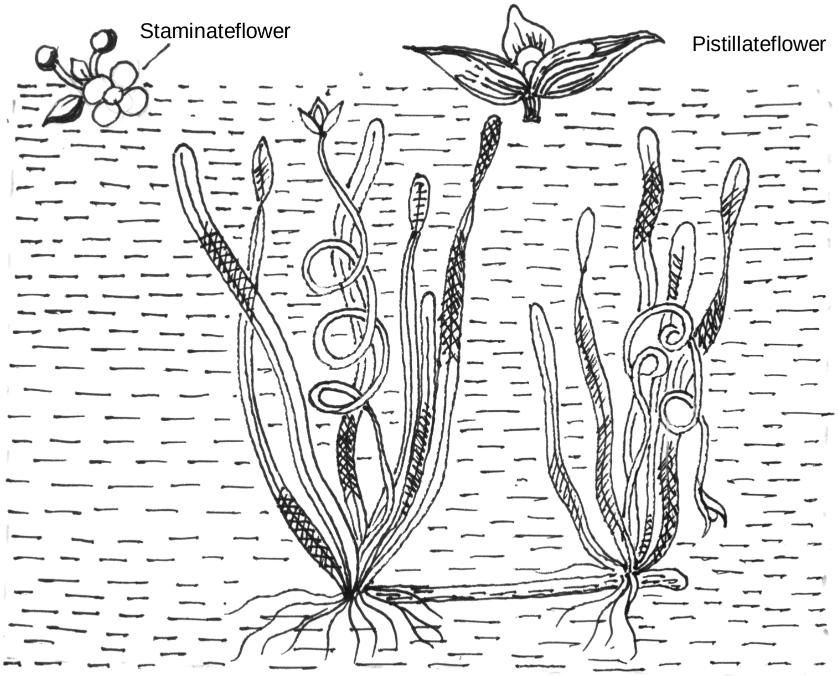


Fig.43:
Young and upright flower of *Aristolochia* sp. with mature stigmas. Small insects can crawl down but cannot come out because of the hairs pointing downward (deflected hairs).

After pollination, the elongated stalk of the pistillate flower undergoes spiral coiling, thereby it again goes under the water (Fig. 44).



6 **Fig. 44 :**Pollinationo(epihydrogamy)invallisneriaspiralis

(vii) In orchid flower highest level of adaptation for cross pollination by insects isdeveloped(Fig.45).The labellum i.e.the posteriormedianmemberofthe inner

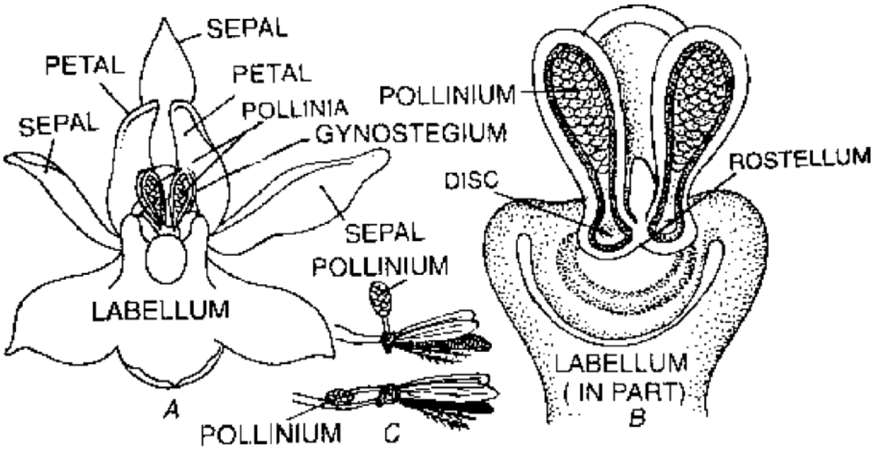


Fig.45: Pollination mechanism in an orchid flower. A—Flower showing different parts. B—Gynostegium only (enlarged). C—One bee carrying pollinia.

Whorl of petal which comes anterior in blooming as due to resupination.
It comes anterior in blooming as due to resupination, is larger in size, and acts as the flag and landing stage for the flies. The rostellum, i.e., the sterile extension from the upper edge of the stigma, secretes a sticky fluid by which the pollinia are adhered to the body of the insects. The gynostemium is formed by the union of stamens and carpels. It is formed bearing two naked pollinia at its top, and below them lies the rostellum concealing the stigmatic surface formed by the fusion of fertile stigmas.

Usually, the bees come and land on the labellum to get nectar concealed in the spur. During its attempt, the insect pushes back the rostellum and even breaks it. Thus, the pollinia are released and get stuck to the leg or forehead of the insect by the disc with the help of the sticky fluid. At first, the pollinia stand erect but due to the flexible nature of the caudicle, they bend down during the movement of the fly. During a visit of an insect to another flower, the pollinia get caught by the sticky fluid of the stigma and gradually the pollen is released. So, cross-pollination is effected.

Adaptations for Self-Pollination

(i) **Cleistogamy:**
It is the condition of being self-fertilized in flowers, usually without opening. Various types of adaptations in cleistogamous flowers belonging to different families are encountered. In *Viola* sp. there is an apetalous flower or a flower having small petals in which anthers are closely applied to the stigma by bending of filaments. Cleistogamy is also observed in the underground flowers of *Commelina benghalensis*. Here, the flowers are minute; they never open from bud condition, so there is no chance of transference of pollen from the anther of another flower to the stigma of the closed flower. However, brightly colored aerial flowers of *Commelina benghalensis* are insect-pollinated. Cleistogamy often occurs in species of *Impatiens, Cardamine, Halenia*, etc. In

certain cases the flowers remain open for a short period of time and then become closed permanently, e.g., *Drosera burmanii, Oxalis corniculata, Portulaca oleracea,* etc.

(ii) **Homogamy:**
It is the condition in which the anthers and stigmas of the flower mature at the same time, so that self-pollination is effected, although not always. Sometimes pollen grains are carried to the stigma by agents like wind, insects, etc. Homogamy is seen in *Argemone mexicana*, *Opuntia dillenii*, *Microcos asiatica*, etc.. In *Mirabilis* sp., self pollination is favoured as the filaments are brought to the contact of the stigma by curling and twining of the same.

Adaptations for cross pollination

There are many devices or adaptations for ensuring cross pollination and these are stated below:

(1) **Dicliny or unisexuality:**
In dioecious plants like *Trichosanthes dioica*, *Borassus flabelifer,* etc., self-pollination is impossible as the flowers are unisexual and contain only one essential member, i.e., either stamens or carpels. In such plants, cross-pollination becomes obligatory. In the case of monoecious plants, however, geitonogamy may take place, e.g., *Zea mays*, *Cucurbita maxima*.

(2) **Dichogamy:**
In some bisexual flowers, the stamens and carpels do not mature at the same time, so that self-pollination is hindered. It is again of two types:
(i) **Protandry or proterandry:**
This is a condition when anthers mature earlier than the stigma, so that immature stigma pollen of the same flower cannot germinate.
e.g., *Helianthus annuus*, *Leonurus sibiricus*, *Hibiscus* sp.
(ii) **Protogyny or proterogyny:**
This is a condition where the stigma matures earlier than the anthers. Here, the mature stigma is pollinated by the pollen of other flowers due to the immature condition of their own anthers.
e.g., *Magnolia grandiflora*, *Michelia champaca*, *Pedilanthus tithymaloides*, *Poinsettia pulcherrima*, *Annona*, *Polyalthia*, species of *Brassica* and members of *Rosaceae*, etc.

(3) **Self sterility or incompatibility:**
Sometimes self-pollination is hindered due to a sterile condition of the pollen of the bisexual flower, and in such cases a flower cannot be fertilized by the pollen of the same flower. It is fertilized by the pollen of another flower, e.g., *Reseda odorata, Solanum tuberosum*, *Petunia axillaris*, *Passiflora* sp., etc.

(4) **Herkogamy:**
When self-pollination becomes impossible due to some physical barrier between the anther and the style. In orchids and members of Asclepiadaceae like *Calotropis procera*, where pollen is aggregated in pollinia, pollination completely depends on the agency of insects. In *Iris* sp. the large outer perianth leaf acts as a landing stage for insects, while the extrorse anthers are concealed by the overarching wide petaloid style—thus a barrier is created between the anther

and the style; as a result, cross-pollination is favoured by insects. In *Gloriosa superba* the anthers dehisce at a distance so that the stigma is out of reach of its own pollen (Fig. 46).

(5) **Heteromorphism:**

This is the phenomenon of the occurrence of two (dimorphic) or three (trimorphic) forms of flowers with the position of anthers and stigmas at different levels, i.e., flowers may have short styles with long filaments and vice versa in the same flower. Due to this condition of the flower, self-pollination is not effected, and cross-pollination takes place between stamens and carpels of similar length.

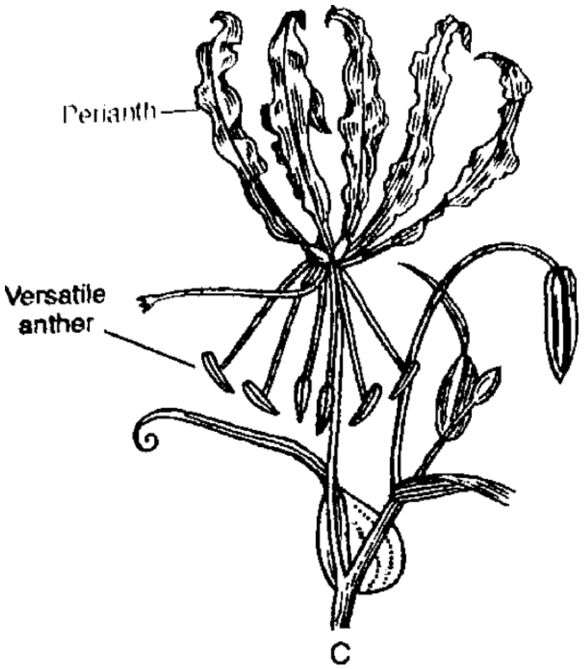


Fig.46: *Gloriosa superba* flower-herkogamy.

(1.1) The dimorphism is found in Primula sinensis (Primulaceae) where one type has long stamen and a short style and the other has short stamen and a long style (Fig. 47). Dimorphism is found in many members of Gentianaceae, Rubiaceae, etc.

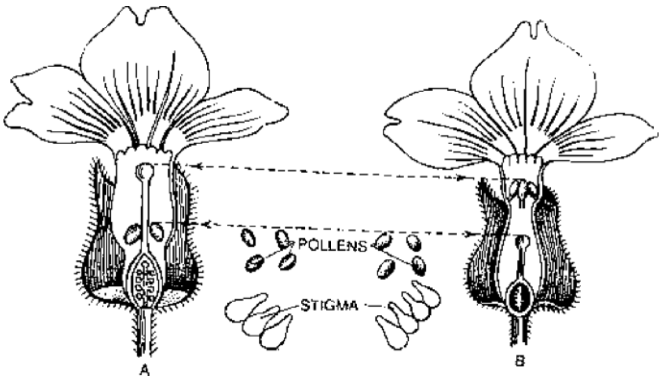


Fig. 47 : Heteromorphism in dimorphic flowers of *Primula* sp. A—Flower having larger gynoecium with higher position of stigma and (st). anthers in lower position with smaller pollens (p). B—Flower having shorter gynoecium with smaller stigma and anthers at higher position with larger pollen grains.

(1.2) The trimorphism is found is *Lythrum salicaria* (Lythraceae), where three different forms of flowers having short, long and mediumsized stamens and styles(Fig.48).ItisalsofoundinO*xaliscorniculata*and*Averrhoacarambola*, *Woodfordia fruticosa floribunda* (= *w*.) etc.

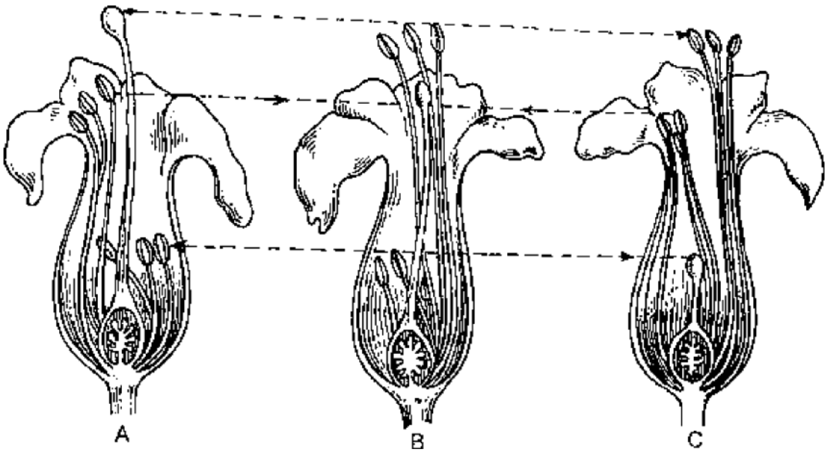


Fig. 48: Heteromorphism in trimorphic flowers of *Lythrum salicaria* with three different lengths of stigma and anther position.

Summary

From the foregoing study the knowledge related to pollination mechanism, adaptations for self and cross pollination can easily be understood.

Questions

1. Describe the method of pollination in the following flowers:
   (a)*Calotropis*, (b)*Ficus*, (c) any orchid
2. Define autogamy.
3. Give an account of adaptations favouring self-pollination of flower.
4. Define allogamy.
5. Give an account of adaptations for cross pollination.

Answers

1. See article no.9.3
2. See article no.9.2
3. See article no.9.4
4. See article no.9.2
5. See article no.9.5

Unit 10: Fertilization

10.0 Objective

From this unit learners can easily understood about the process of double fertilization.

10.1 Introduction

Fertilization or syngamy is the essential biological process of sexual reproduction in which the union of two dissimilar sexual cells i.e., union male and female gametes takes place resulting in the formation of zygote.

.

2 **Double Fertilization**

3 Fertilization was first discovered by Strasburger in 1884. It is a process where male and female gametes fuse with each other and result in the formation of an embryo.
Fertilization is the essential biological process of sexual reproduction. It is also termed as syngamy or fecundation.

In angiosperms the female gametophyte, i.e., the embryo sac, remains deep in the ovarian cavity, quite a long distance from the stigma. The pollen grains, after being liberated from the anther, reach the stigma and the viable pollen germinates. During germination, the pollen grain develops a pollen tube which grows through the style and reaches the ovule where it releases the male gametes near the egg.

The generative cell divides to form two male gametes, either within the pollen grain before germination or inside the pollen tube during germination. Only the distal part of the pollen tube contains the living cytoplasm with the tube nucleus and generative nucleus (or a tube nucleus and two male nuclei produced from the generative nucleus).

The growth of the pollen tube is stimulated by the sugary substances secreted by the stigma. The pollen tube, soon after germination, passes through the stigmatic papillae and then passes into the style.

After reaching the top of the ovary, the pollen tube may enter through the micropyle with its nuclei – called porogamy. Sometimes the pollen tube may enter the ovule in a roundabout way through the chalaza – known as chalazogamy or basigamy or a porogamy as in *Casuarina* sp., *Betula* sp., *Juglans* sp., etc. In a few cases the pollen tube enters the ovule through the funiculus or the integuments – this is called mesogamy or a porogamy as in *Alchemilla* sp. and *Cucurbita* sp. On penetrating the integuments of the ovule, the pollen tube ultimately penetrates the wall of the embryo sac.

After penetrating the wall of the embryo sac, the pollen tube may pass between one egg and a synergid, or between the embryo sac wall and a synergid, or directly into a synergid. Usually, one synergid is destroyed by the impact of the pollen tube while the other remains intact for a brief period. In certain cases, the synergids may degenerate before the entry of the pollen tube, which indicates that they are not necessary for fertilization.

Ultimately, the tip of the pollen tube bursts and both male gametes are set free (Fig. 49).

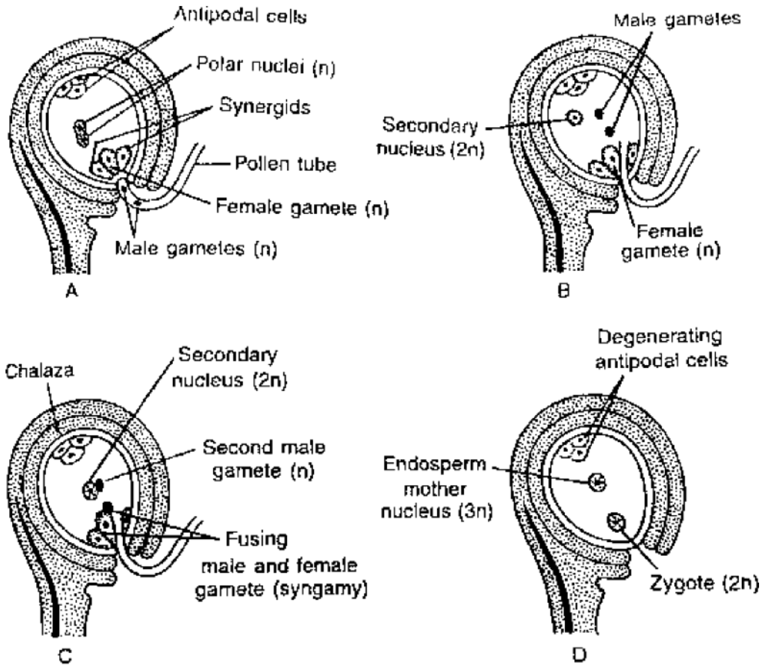


Fig.49: A-D. L.S. of ovules showing different stages of fertilisation

One of the male nucleus fuses with the egg nucleus to form oospore or zygote (2n) while the other male nucleus fuses with the secondary or fusion nucleus—resulting in the formation of primary triploid endosperm nucleus (3n). Thus, there is twice fertilization in angiosperms—one of the male gametes fuses with the egg nucleus and the other with the secondary or fusion nucleus, and this phenomenon is known as double fertilization. It was first observed by Nawaschin (1898) in *Lilium martagon*. The fusion of the second male gamete (n) with the diploid secondary nucleus (2n) is the triple fusion, and the resultant nucleus is the triploid endosperm nucleus (3n). The zygote or oospore forms the first cell, i.e., the mother cell of the embryo.

10.3 Summary

From detail study of this unit double fertilization and its mechanism will be understood.

10.4 Questions

6. Distinguish fertilization and double fertilization.
7. Define fertilization.

8. What is meant by mesogamy?
9. Describe the process of double fertilization met in angiosperm with suitable illustration.

10.5 Answers

6. See article no.10.2
7. See article no.10.2
8. See article no.10.2
9. See article no.10.2

Unit 11: Seed

11.0 Objective

Learners will know about the seed structure and appendages.

Learners will be able to describe various modes of seed dispersal mechanism.

11.1 Introduction

Mature integumented fertilized ovule is called as seed. It is the characteristic feature of spermatophytes i.e., seed plants. Angiospermic plants are closed seeded plants i.e. seeds are covered within the fruit while in gymnosperms seed are naked i.e., seeds are not enclosed within the fruit. The seeds of angiosperms may be monocotyledonous and dicotyledonous as per the number of cotyledons present.

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Seed structure; appendages and dispersal mechanism

Mature integumented, fertilized ovule is the seed. It is the characteristic feature of spermatophytes, i.e., seed plants.
Angiospermic plants are closed seeded plants, i.e., seeds are covered within the fruit, while in gymnosperms seeds are naked, i.e., seeds are not enclosed within the fruit.
The seeds of angiosperms may be monocotyledonous or dicotyledonous as per the number of cotyledons present.

Structure of seed
A typical mature seed of angiosperms consists of (i) seed coat and (ii) kernel.

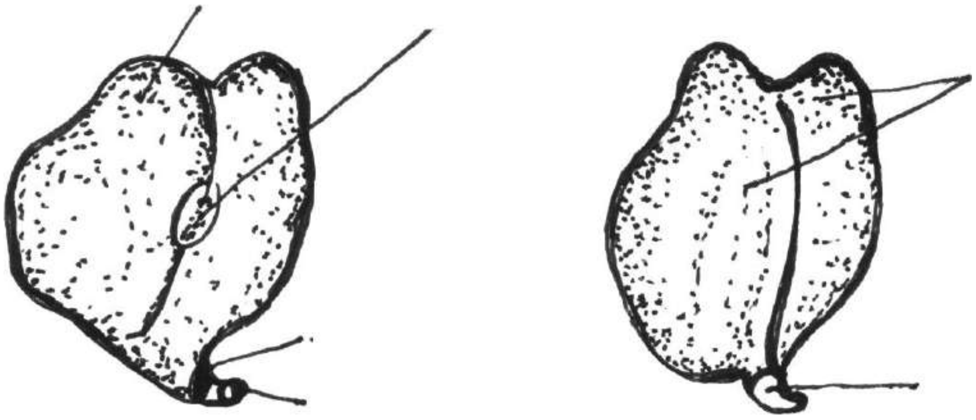
(i) **Seed coat:**
It is the protective covering of the seed which develops from the integuments of the ovule. It is of two types, i.e., testa and tegmen. Testa is the hard outer layer and tegmen is the thin, papery inner layer.
At one end of the testa there is a scar known as the hilum. The hilum is the position of attachment of the seed with its stalk, the funiculus. Near the hilum a small opening is present, known as the micropyle, through which water enters the seed. Sometimes a ridge is present beyond the hilum, opposite the micropyle, known as the raphe.
Tegmen is much thinner than the testa. It is absent in *Pisum sativum* and appressed in *Cicer arietinum*.

(ii) **Kernel:**

The inner part within the seed coat is called the kernel. It consists either of the embryo only, as in exalbuminous seeds like *Cicer arietinum*, or the embryo enclosed within the endosperm in albuminous seeds like *Oryza sativa*, *Triticum aestivum*, etc. Sometimes, the embryo is present along with both endosperm and perisperm, as in *Elettaria cardamomum*.

(a) **Embryo:**
It remains enclosed in a seed. The embryo consists of the cotyledon and the tigellum. **Cotyledons:** These are the leaves of the embryo. The number is either one, as in monocotyledons, or two, as in dicotyledons. Sometimes cotyledons store food and become fleshy, and in a few cases they do not store food, remaining thin and papery. The cotyledons remain attached to an axis—the tigellum—and the point of attachment is known as the cotyledonary node (Fig. 50).

Fig.50: Structure of dicotyledonous exalbuminous seeds. a – structure of gram seeds. b – structure of pea seed.



Tigellum (axis):
It is the main axis of which one end is pointed and protrudes out of the cotyledon. It lies next to the cotyledonary node and is known as the radicle. The other end of the tigellum is the plumule. In monocotyledonous seeds, both the radicle and the plumule remain covered by protective sheaths, known as coleorhiza and coleoptile respectively (Fig. 51).

The portion of the axis above the point of attachment of the cotyledon is called the epicotyl, and its lower portion, which lies below the point of attachment of the cotyledon, is called the hypocotyl (Fig. 51).

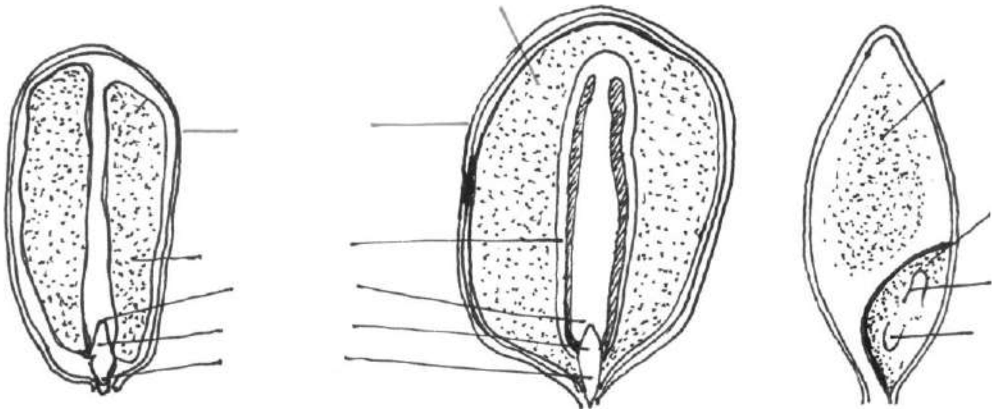
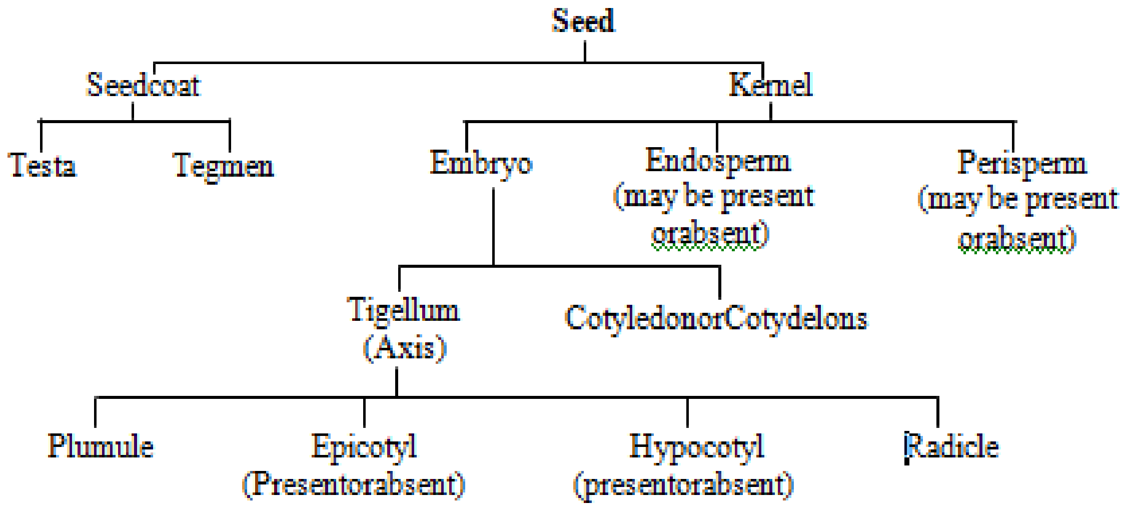


Fig. 51 : General structural differences among the four different types of seeds : A. Dicotyledonous exalbuminous (Non-endosperonic),B.Dicotyledonousalbuminous(endospermic),C.Monocotyledonousalbuminous(Endospermic).

(a) **Endosperm:** Endosperm is the food reservoir of seed. It may be starchy e.g. *Triticum aestivum,* oily in *Brassica nigra*,proteinaceous in *Cicer arietinum.*

(b) **Perisperm:** It is the remnant of nucellus of ovule and is also nutritive in function.

Generalstructureofseed



Dispersal

Dispersal is the phenomenon of transfer of plants to a distant place. Seeds are usually formed in abundance so that they may be distributed over a wide area to ensure the multiplication of plants. If all the seeds fall near the mother plant and germinate there, the new plants cannot have healthy growth due to overcrowding of population in a small area. The overcrowding of the seedlings results in the death of most of the plants due to insufficient space, light, air and nutrition.
Seeds are not able to move independently from one place to another—so they have to depend on some agents like wind, water, animals, etc., for their dispersal, and thus the morphological construction of seeds varies according to dispersal agencies. These characteristic morphological features are discussed below in respect to dispersal mechanism by different agencies.

Dispersal by Wind

Seeds which require wind as an agent for dispersal are known as anemochorous. For wind dispersal, the seeds should be light in weight so that they may fly for long distances. Seeds which are wind dispersed have any of the following devices for efficient dispersal:

(A) **Light weight:**

Very small and tiny dry seeds of orchids and the grains of grasses are easily carried by wind due to their light weight (Fig. 52a).

(B) **Winged fruits and seeds:**

Wing-like expansion of different types may develop in fruits and seeds which help them to float in air.
(i) Wings may develop from the seed coat, i.e., the testa. For example, *Moringa olifera* (Fig. 52b), *Oroxylum indicum, Swietenia mahagani.*

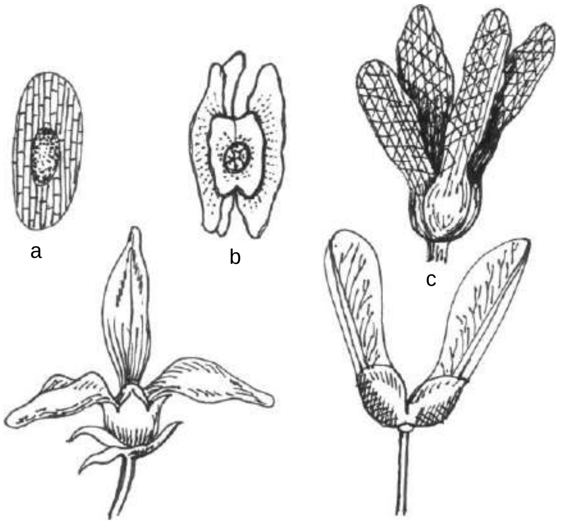


Fig.52: Fruitsandseedsadoptedforwinddispersal:a. Minute and Light seeds of orchid, b–c. Winged fruits and seeds. Wings develop flour seed coat of *Moringa*, (b) *Oroxylum, Shorea*, (c) Pericarp expands into wings of *Niptage* (d) and *Acer* (e).

ii) Wings may develop from persistent sepal, e.g., *Dipterocarpus* sp., *Shorea robusta* (Fig. 52c), etc.

(iii) Wings may develop from the pericarp of fruit, e.g., *Hiptage benghalensis* (Fig. 52d), *Acer pseudoplatanum* (Fig. 52e), etc.

(C) **Parachute mechanism:**
Some seeds and fruits are provided with appendages acting as a parachute by which they remain in the air for a long time and can disperse over long distances. The seed appendages are:

(i) **Comma:**
A tuft of hairy outgrowth of the testa at one end or both ends of seeds helps to disperse them over long distances, e.g., seeds with one comma as in *Calotropis procera* (Fig. 53a) and comma at both ends of seed, e.g., *Alstonia scholaris*.

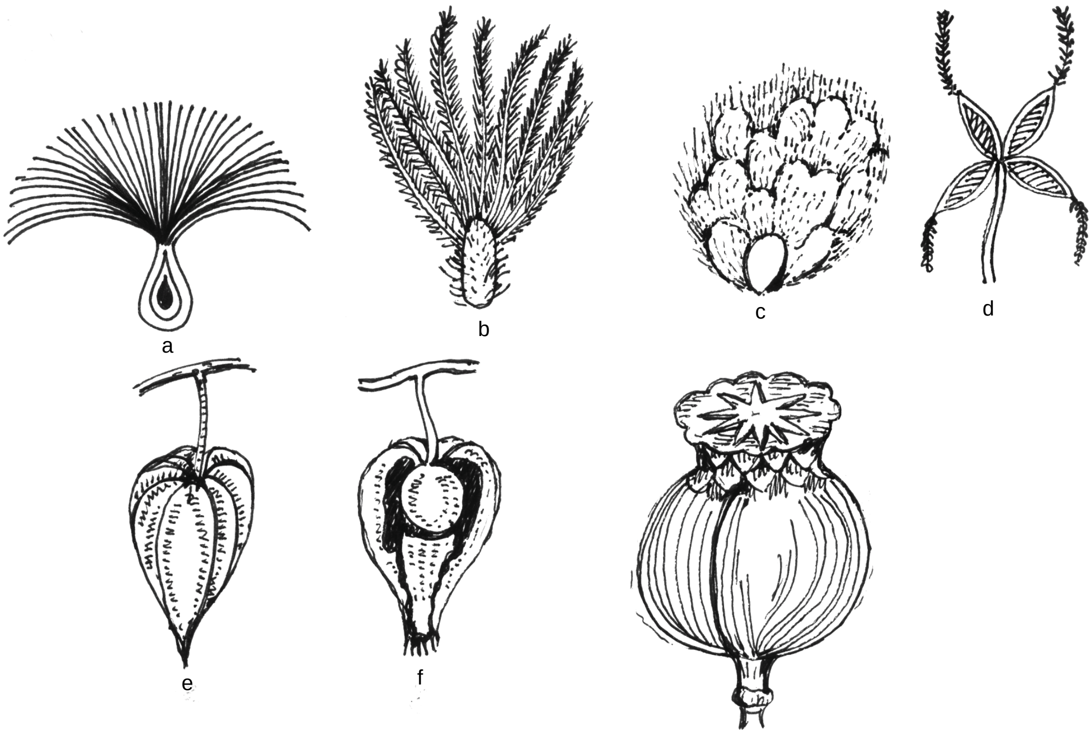


Fig. 53 : **Seeds adopted for wind dispersal : a. Coma of *Calotropis,* b. Pappus of *Tridax Procumbens,* C. *Hairy* outgrowth on seeds of *Bombax Ceiba*, d. Persistent hairy style of *Clematis gouriana*, e. Ballon-Shaped appendages (by inflated calys of *Physalis*), f. Single enlaryged capsule of *P. Somuiferum.***

(ii) **Pappus:** It is the modification of calyx lobes in the form of hairs. The fruits of *Vernonia cinerea*, *Blumea lacera*, *Ageratum conyzoides*, *Tridax procumbens*, etc., have a pappus to help dispersal (Fig. 53b).

(iii) **Hairy outgrowth on seeds:** This type of structure is present all over the seed coat, i.e., on the testa, as seen in *Gossypium herbaceum*, *Bombax ceiba*, which helps to disperse the seed over long distances (Fig. 53c).

(iv) **Persistent hairy style:** This is seen in fruits of achenes, by means of which fruits can float in the air and disperse over long distances, e.g., *Clematis gouriana*, *Ceiba pentandra* (Fig. 53d), *Naravelia zeylanica*, etc.

(v) **Balloon-shaped appendages:** Balloon-shaped appendages are formed by the modification of different parts of the plant. They help the fruit and seed to remain in the air for a longer period. They are formed by the inflated, accrescent calyx in *Physalis minima* (Fig. 53e), inflated ovaries of legumes in *Colutea arborescens*, inflated ovary of *Cardiospermum heticacabum*, etc.

(D) **Censor mechanism:** It is the mechanism by which very small seeds are liberated slowly from the fruits through minute pores, e.g., *Antirrhinum majus*, *Papaver somniferum* (Fig. 53f), etc.

Dispersal by Water

The aquatic plants and the plants growing on the banks of rivers or seashores disperse their seeds and fruits by water currents for long distances. In such plants, the seeds and fruits generally develop floating devices in the form of spongy tissues or fibrous coats, which are waterproof and buoyant. The plants which require water as an agent for dispersal are termed hydrochorous. The fruitlets may be embedded in the spongy and watertight thalamus and can be carried away by water currents, as in *Nelumbo nucifera* (Fig. 53g). In the fruit of *Cocos nucifera*, the fibrous mesocarp acts as a floating device; the hard endocarp protects the embryo from external injury—so the fibrous coconut fruit is capable of floating long distances in water without suffering any damage.

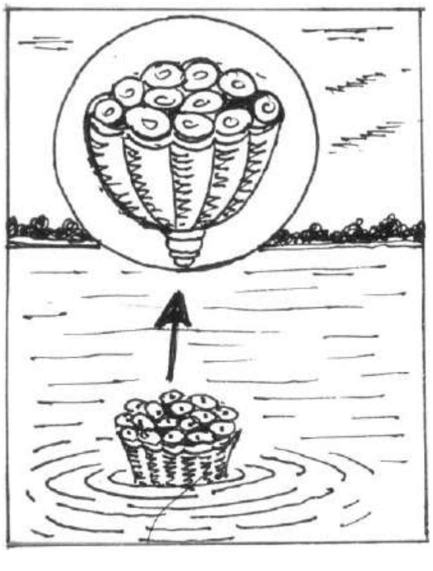


Fig.53g: DispersalbyWater:Lotus, Nelumbo nucifera.

injury. Such type of floating devices is also seen in Arecaceae, Catechu and Nipafruticans, etc.

In few cases, the seeds have air spaces in their coverings, which enable them to float on water and can easily be dispersed by water current, e.g., Sagittaria sagittifolia, Alisma plantago, etc.

Dispersal by animals

Dispersal by means of human beings and other animals such as grazing cattle, birds, etc. is by no means infrequent. Thus, the fruits and seeds with their adhering structures are dispersed by animals. Plants having such devices are called zoochorous.

The common examples are the curved outgrowths of prickly bodies on the pericarp of *Xanthium strumarium*, *Triumfetta bartramia*, *Urenalobata*, etc. (Fig. 54a, b).

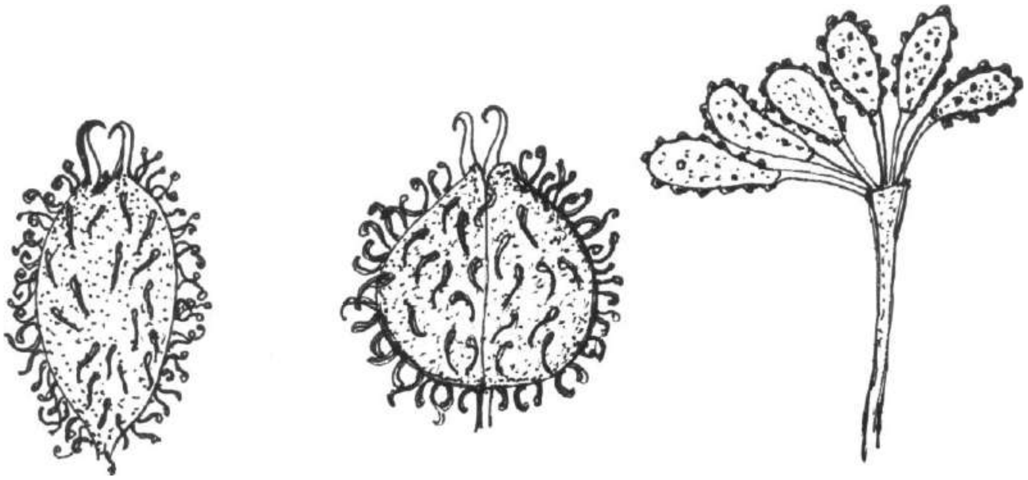


Fig.54: Dispersalby animals: A.By spinesin Achyranthes,B. inXanthium, C.inUrena

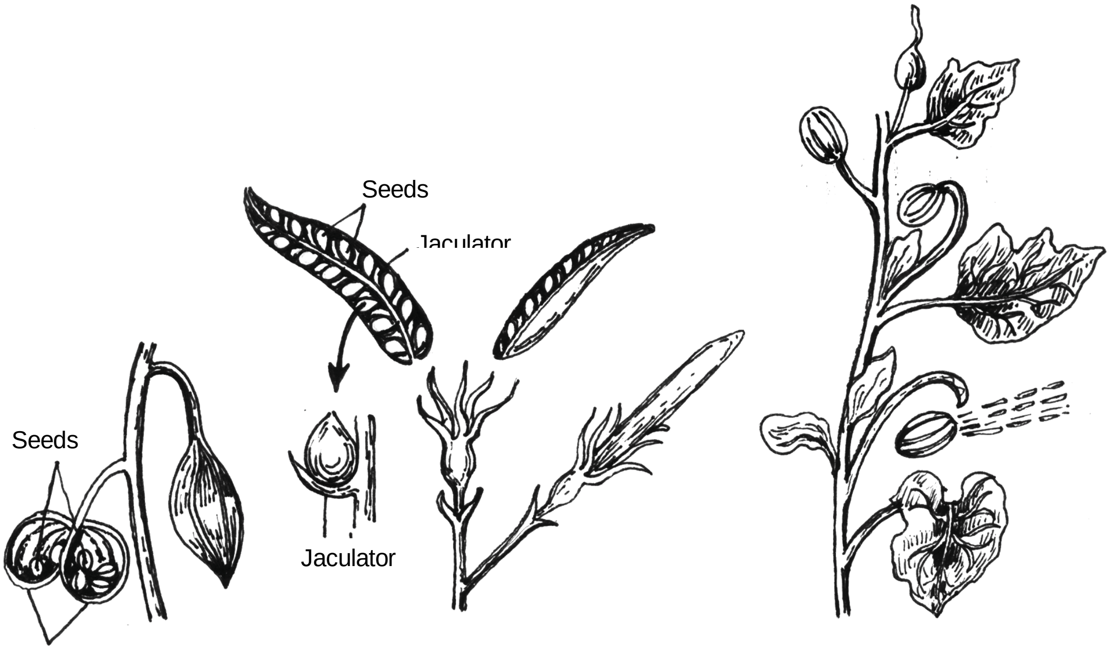
The fruits provided with spines become attached to the body of animals, including human beings, and are dispersed at distant places, as in the case of Achyranthes aspera, Andropogon aciculatus, etc.

In the fruits of Martynia diandra – the fruits get attached to the bodies of grazing animals by means of the claws and can be carried to distant places. Sharp, rigid spines on the fruits of Tribulus sp. help in dispersal when those get embedded into the foot of hoofed animals. The fruits of Boerhavia diffusa, Desmodium gangeticum, Cleome viscosa, etc. are provided with sticky glands (Fig. 54c) so that they stick to the bodies of grazing animals and are thereby dispersed.

Special morphological elaboration for dispersal by birds and flying foxes is found in succulent berries, syconus, etc. The seeds of such fruits have a resistant, thick testa. The fruits are eaten by birds; these seeds remain undigested in the intestine and are excreted, where they germinate. The growth of *Ficus benghalensis* in old buildings is due to such a mode of dispersal by birds.

Dispersal by Explosive Mechanism

Explosive and dehiscence mechanisms of capsules in many plants are means of dispersing seeds to a certain distance. The fruits of *Impatiens balsamina* and *Oxalis* sp., when touched, burst with a sudden jerk and a little sound; as a result, the seeds are scattered to a distance (Fig. 55a). The ripe fruits of *Abrus precatorius*, *Clitoria* sp., etc., suddenly burst on twisting and thereby scatter the seeds. The mature fruits of *Andrographis paniculata*, *Ruellia tuberosa* (Fig. 55b), when in contact with moisture, suddenly burst with an explosive sound and the seeds are dispersed in the nearby regions. Sometimes these seeds remain attached with hook-like projections known as jaculators or retinacula, which help in the dispersal of seeds to a distance for members of Acanthaceae.



The long pods of Bauhinia vahlii explode suddenly, producing a great loud sound and scatter the seeds. In Ecballium elaterium (Fig. 55c), violent explosive ejection of seeds at the point of attachment of the fruits with the stalk is noted when the fruits get detached from the stalk.

Summary

From detail study of this unit general structure of seed as well as appendages and their mode of dispersal mechanism will be understood.

Questions

10. Define seed.
11. Describe different structures of seeds.
12. Describe the mechanism of dispersal of fruits and seeds through different agencies with examples.
13. Mention different agents by means of which seed and fruits are dispersed.
14. State as how the following seeds are dispersed—(a) *Moringa*,(b) *Alstonia*, (c) *Hiptage*, (d) *Gossypium*,(e) *Nymphaea*,(f) *Cocos nucifera*,(g) *Xanthium*

Answers

10. See article no.11.2
11. See article no.11.3
12. See article no.11.4
13. See article no.11.4

Unit 12: Endosperm

12.0 Objective

From the study of this unit learners can gather the knowledge regarding the development of both dicotyledonous and monocotyledonous embryos. In addition to this learners can describe the different form of endosperm formation and its function.

12.1 Introduction

After fertilization, generally the fertilized egg i.e. oospore divides immediately after the first division of the primary endosperm nucleus but sometimes it divides earlier than the primary endosperm nucleus. The endosperm makes the main source of food for the embryo. In gymnosperms the endosperm is haploid (n) and forms a continuation of the female gametophyte. On the other hand, in angiosperm it is formed mostly as the result of a fusion of the two polar nuclei and one of the male gametes. As all the three nuclei taking part in the fusion are haploid, the endosperm becomes triploid (3n). Generally the endosperm is triploid but haploid, tetraploid and polyploidy endosperms are also known. Generally the endosperm nucleus divides after the division of oospore but in many cases endosperm is formed seen before the first division of oospore.

Types of Endosperm

There are three general types of endosperm formation, and these are named as: (a) nuclear type, (b) cellular type, and (c) helobial type.

(a) **Nuclear type:**
Here, the first division and usually several of the following divisions are unaccompanied by wall formation. The nuclei may either remain free or, in later stages, they may become separated by walls. As division progresses, the nuclei are pushed toward the periphery, and thus a large central vacuole is formed. Often, the nuclei are specially aggregated at the micropylar and chalazal ends of the embryo sac and form only a thin layer at the sides. Generally, the endosperm nuclei in the chalazal part of the embryo sac have been observed to be larger than those in the micropylar end (Fig. 56). The number of free nuclear divisions varies in different plants. In *Primula, Malva, Juglans,* etc., several hundred endosperm nuclei are formed which are seen lining the wall of the embryo sac. In *Melastoma* there is no wall formation. In *Asclepias,*

Calotropis, *Rafflesia*, etc., wall formation occurs at the very early stage when only 8 or 16 nuclei are formed, and in *Coffea* at the 4-nucleate stage. The wall formation generally progresses from the periphery of the embryo sac toward the centre or from its apex toward the base.

(b) **Cellular type:**
In this type, the first and most of the following divisions are accompanied by wall formation, and thus the embryo sac is divided into several chambers, some of which may contain more than one nucleus. The first wall is usually transverse but sometimes vertical or oblique, and in some cases the plane of division is not constant (Fig. 57).

(c) **Helobial type:**
This type is frequently found in the members of the order Helobiales. It is intermediate between the nuclear and the cellular types. In this type, the first division is followed by a transverse wall, resulting in a micropylar and a chalazal chamber. Further divisions are generally free nuclear and may take place in both chambers, but the main body of the endosperm is formed by the micropylar chamber only (Fig. 58).

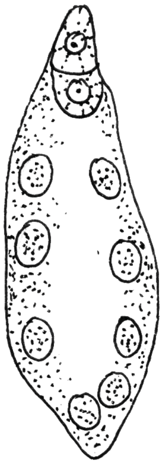


Fig.56

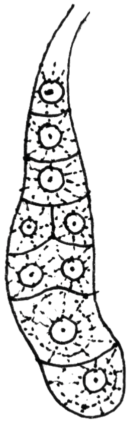


Fig.57

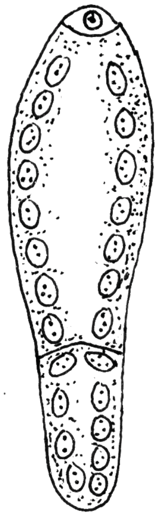


Fig.56: Developmentofendosperm;Nucleartype
Fig.57: Cellulartype
Fig.58: Helobialtype

Structure and functions of endosperm

Endosperm is meant for the storage of food and cells of it are usually thin-walled, large, isodiametric, and without pits. But in certain cases where hemicellulose makes the main food reserve, the walls of endosperm become very much thickened and pitted. The outermost layer of the endosperm of the members of Gramineae acts like a cambium and produces thin-walled cells toward the inner side. These cells remain filled with starch. After some time, this so-called cambial layer ceases to function and converts into an aleurone layer. It is thought that this layer secretes certain enzymes which bring about the assimilation of the food stored in the endosperm and make it available for the developing embryo.

Available to the embryo. In certain cases where the integuments are absent, the cells of the outermost layer of endosperm become suberized and hence a protective layer is formed. Since there is heavy deposition of starch grains, the nuclei become quite deformed and disorganized. In fully ripe grain, the endosperm makes a physiologically dead tissue.

As the endosperm develops, it fills up the nucellus. In many seeds the endosperm is seen at maturity—although it is always formed at the initial stage of embryo development. During the process of development of the embryo, the food stored up in the endosperm is continuously drawn up by the developing embryo and thus completely exhausted. Such seeds are known as exalbuminous or non-endospermic, e.g., gram, pea, bean, tamarind, orchid, etc. On the other hand, where endosperm grows vigorously and is not completely exhausted by the developing embryo, the seed is known as albuminous or endospermic, e.g., castor, poppy, rice, wheat, barley, palms, grasses, etc. In most cases, as the endosperm develops, it completely fills up the nucellus space and no nucellus is found in the seed in such cases. However, in few cases, as in *Nymphaea*, *Mirabilis*, *Zingiber*, etc., the nucellus persists and develops into a nutritive tissue like the endosperm, called the perisperm.

Endosperm plays an important role, as it is the main source of food for the growing embryo. In angiosperms the endosperm forms after fertilization and is triploid in nature. In gymnosperms the endosperm forms before fertilization and is haploid in nature.

Mosaic Endosperm

In some angiosperms, there is a lack of uniformity in the tissues of the endosperm, which is termed as mosaic endosperm. For example, in *Zea mays*, patches of two different colours are seen forming a sort of irregular mosaic pattern. According to Webber (1900), the second male nucleus fails to fuse with the polar nuclei and both divide separately, giving rise to nuclei of two distinct characters. These nuclei are intermingled during free nuclear division and thus the mosaic endosperm develops. According to Mahaeswari (1950), it is possible that sometimes only one of the polar nuclei is fertilized while the other divides independently, resulting in the formation of mosaic endosperm. Clark and Copeland (1940) have given the most reasonable explanation for the development of mosaic endosperms. According to them, there is either aberrant behavior of the chromosomes in mitosis or there are somatic mutations which explain the problem.

12.5 Summary

From detail study of this unit it can be concluded that the knowledge regarding the types, structure and functions of endosperm as well as the distinction between dicot and monocot embryo may be gathered.

12.6 Questions

1. Describe briefly the formation of helobial and cellular endosperm.
2. Write notes on nuclear endosperm.
3. Write notes on the function of endosperm and mosaic endosperm.

12.7 Answers

14. See article no.12.2
15. See article no.12.2
16. See article no.12.3 & 12.4

Unit 13: Embryo

13.0 Objective

This unit will help learners to know about the role of endosperm in growing embryo.

Learners will be able to discuss the embryo-endosperm relationship.

13.1 Introduction

After fertilization, zygote or oospore develops into an embryo. The oospore before it actually enters into the process undergoes a period of rest. Generally the zygote divides immediately after the first division of the primary endosperm nucleus but sometimes it divides earlier than the primary endosperm nucleus. Unlike gymnosperms where the early stages of development show free nuclear divisions the first division of zygote is always followed by a wall-formation resulting in a two-celled pro-embryo. Practically there are no fundamental differences in the early stages of the development of the embryos of monocot and dicot. But in later stages there is a marked difference between the embryos of dicotyledonous and monocotyledonous plants.

Embryo of dicot and monocot

After fertilization, the fertilized egg is called a zygote or oospore which develops into an embryo. Generally, the zygote (oospore) divides immediately after the first division of the primary endosperm nucleus, but sometimes it divides earlier than the primary endosperm nucleus. Unlike gymnosperms, where the early stages of development show free nuclear divisions, the first division of the zygote is always followed by wall formation resulting in a two-celled structure called the proembryo. Practically, there are no fundamental differences in the early stages of the development of the embryos of monocots and dicots. However, in later stages there is a marked difference between the embryos of dicotyledonous and monocotyledonous plants.

Development of Embryo in Dicots

Capsella bursa-pastoris of the family Brassicaceae is considered as the typical example to study the development of a dicotyledonous embryo.
Initially, at the time of development of the embryo, the zygote divides transversely to form a two-celled structure. Of these two cells, the innermost one is termed the terminal cell and the outermost is the basal cell (Fig. 59).

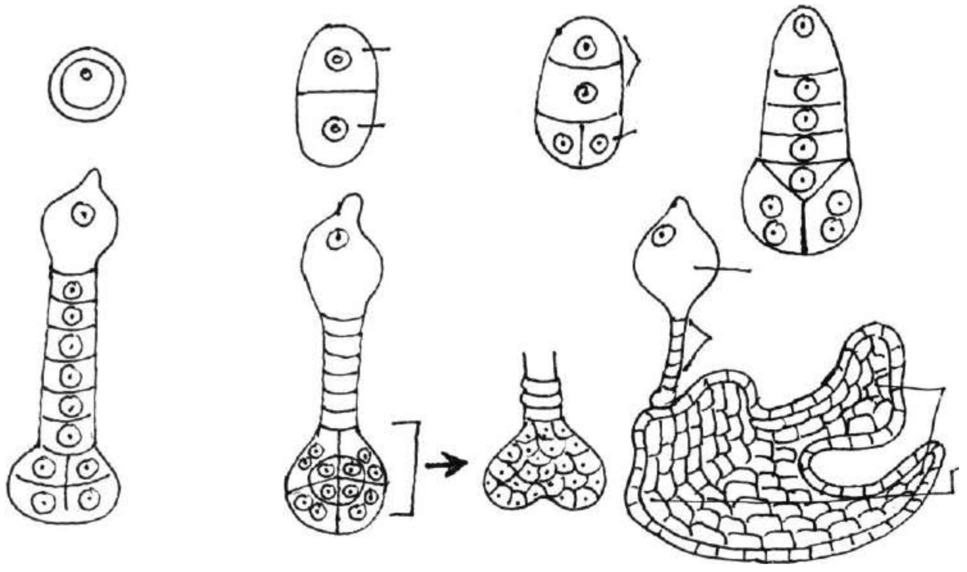


Fig.59: Stages in the development of a typical icotembryoinCapsellabursa-Pastoris

Basal cell then divides transversely to form a two-celled structure. The terminal cell also divides vertically once. Thus, a collection of a four-celled structure is formed and looks like an inverted “T”. This is collectively termed as the proembryo.

After this, each cell out of the two terminal cells divides transversely first and then again divides transversely at its right angle, and by this a quadrant of 4 cells is formed. This quadrant further divides transversely to produce an octant. The apical part of the stem and cotyledons are formed from the basal four cells of the octant, and from the upper four cells of the octant the hypocotyl, along with the inner core of the radicle, is formed.

In the meantime, two basal cells of the proembryo divide repeatedly to form multilayered suspensor cells. The topmost cell of the suspensor forms a vesicle by swelling, which acts as the suspensor (haustoria), and the two lowermost cells act as the hypophysis. The epidermis, cortex, and root cap of the radicle are formed by the division of the hypophysis. In the next stage, the development of the embryo takes place freely and the embryo assumes the shape of a heart.

After this, through overlapping cell divisions, two cotyledons are formed by the elongation of two apical segments of the heart-shaped embryo and remain as the hypocotyl. Suspensor cells help in holding the embryo within the nucellus, which degenerates with the maturity of the embryo.

Development of Embryo in Monocots

There is no essential difference between the early cell divisions of the proembryo in monocotyledonous and dicotyledonous plants, but the mature embryos are quite different in the two groups. Here, the embryogeny of *Sagittaria sagittifolia* has been considered as one of the typical examples of monocotyledonous plants.

The zygote divides transversely, forming a terminal cell and a basal cell. The basal cell, which is larger and lies towards the micropylar end, does not divide again but is transformed directly into a large vesicular cell. The terminal cell divides transversely, forming two cells. Of these, the lower cell divides vertically to form a pair of juxtaposed cells, and the middle cell divides transversely into two cells. In the next stage, these two cells further divide vertically to form quadrants. The cell next to the quadrants also divides vertically, and the cell next to the upper vesicular cell divides several times transversely to form the octants, the eight cells being arranged in two tiers of four cells each. With the result of periclinal division, the dermatogen is formed. Later, the periblem and plerome are also differentiated. All these regions, formed from the octants afterwards, develop into a single terminal cotyledon. The lowermost cell of the three-celled suspensor divides vertically to form the plumule or stem tip. The cells below the suspensor form the radicle. The upper 3–6 cells contribute to the formation of the suspensor (Fig. 60).

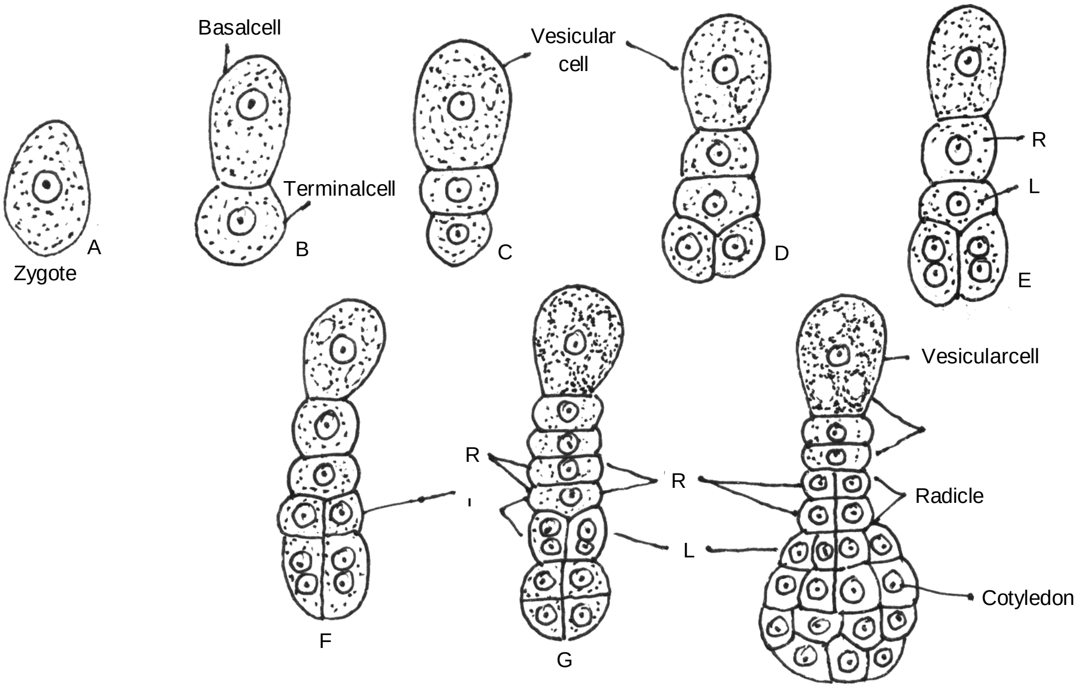


Fig. 60: Stages in the development of atypical dicot embryo in *Capsella bursa-pastoris*.

Embryo-endosperm relationship

Embryo and endosperm maintain a strong relationship between them. Both are formed within the ovule. The zygote, i.e., oospore (2n), is formed within the ovule through the unification of the egg nucleus (n) with a male nucleus (n), which gives rise to the embryo, the cells of which are diploid (2n). One of the male gametes fuses with the secondary or fusion nucleus, i.e., definitive nucleus (2n), to produce a triploid (3n) endosperm nucleus, from which endosperm is formed. This endosperm supplies nourishment to the growing embryo. The ovule, together with the embryo and endosperm, as a whole gives rise to the seed, which remains covered by the seed coat developed from the integuments.

13.4 Summary

Form the study it can be concluded that the knowledge regarding the distinction between dicot and monocot embryo may be gathered. More over knowledge related to embryo endosperm relationship could also be known. Embryo and endosperm both are formed within the ovule, which are co-related with each other.

13.5 Questions

4. Define embryo.
5. With suitable illustration describe development of typical dicot embryo.
6. Write notes on embryo-endosperm relationship.

13.6 Answers

17. See article no.13.2
18. See article no.13.2.1
19. See article no.13.3

Unit 14: Apomixis and Polyembryony

14.0 Objective

From study of this unit learners get a better idea in relation to the formation of plants by substituting normal sexual cycle.

Learners will be able to discuss how sexual reproduction is substituted by an asexual process which does not involve any nuclear fusion.

Learners can easily understood about the knowledge related to true and false polyembryony along with cleavage polyembryony formation technique.

Introduction

During the normal sexual cycle, fertilization leads to the formation of an embryo and later on a seed. New plants are produced by the germination of seeds. Later, male and female gametophytes are formed on the plant after meiosis. This normal sexual cycle involves both fertilization and meiosis. This haploid and diploid phase regularly alternate with each other and is known as the alternation of generations.
However, in many plants the normal process of sexual reproduction is substituted by an asexual process. This phenomenon of substitution of the sexual process by an asexual process is known as apomixis, and the plant which shows this is called an apomictic plant.

Occurrence of more than one embryo in the seed is known as polyembryony. In angiosperms, polyembryony may be of different types, such as:
(a) Cleavage polyembryony;
(b) Origin of embryos from cells of the embryo sac other than the egg;
(c) Embryos developing from cells outside the embryo sac; and
(d) Embryos originating from other embryo sacs in the ovule.

Apomixis

In many plants, the normal process of sexual reproduction is substituted by an asexual process. So, the phenomenon of substitution of the sexual process by an asexual method is known as apomixis. The plant which shows this phenomenon is called an apomictic plant.
The term ‘apomixis’ was coined by Winkler (1908) and accordingly apomixis may be defined “as the substitution of the sexual process which does not involve any nuclear fusion.” In the case of apomixis, an asexual method of the formation of the embryo takes place instead of normal production by fertilization.

According to Maheswari (1950), apomixis may be subdivided into the following types:
(i) **Non-recurrent apomixis:**
In this type the megaspore mother cell undergoes the usual meiotic divisions and a haploid embryo sac is formed. Here, the embryo arises either from the egg (haploid parthenogenesis) or from other cells of the gametophyte (haploid apogamy). In this case, haploid plants are always produced. The produced plants contain only one set of chromosomes, and as haploid plants they are generally sterile and do not reproduce sexually anymore.
This type of apomixis is found in several species such as *Solanum nigrum, Lilium martagon, Erythraea centaurium, Orchis maculata, Nicotiana tabacum,* etc.

(ii) **Recurrent apomixis:**
Here, the female gametophyte, i.e., the embryo sac, is diploid; all the nuclei of the embryo sac contain diploid (2n) chromosomes because there is no reduction division in the number of chromosomes. This type of diploid embryo sac is originated either from a cell of the archesporium (generative apospory) or from some other cell of the nucellus (somatic apospory). The embryo may develop either from the diploid egg cell (called diploid parthenogenesis) or from some other diploid cell of the embryo sac (diploid apogamy).
Generative apospory is reported in *Eupatorium glandulosum*, *Parthenium argentatum*, etc.
Somatic apospory is known from *Hieracium excellens* and *H. aurantiacum*.

(iii) **Adventive embryony or sporophytic budding:**
This type of apomixis is also known as sporophytic budding. Here the developed embryo sacs may be haploid or diploid, but the embryos do not arise from the cells of the gametophyte; they arise only from the cells of the nucellus or the integument. There is no alternation of generations, as the diploid tissues of the sporophyte directly give rise to the new embryo.
Adventive embryony has been frequently observed in *Citrus* sp., *Euphorbia dulcis*, *Capparis frondosa*, *Mangifera indica* and *Hiptagema dablata*.

(iv) **Vegetative propagation by bulbils or other propagules:**
Here the flowers are replaced by bulbils or other vegetative propagules which germinate while still on the plant, forming new plants. As this type is merely a form of vegetative reproduction, many workers do not consider it as apomixis.
Bulbils have been reported in *Globba bulbifera, Allium sativum*, *Dioscorea bulbifera*, *Agave* sp., *Oxalis* sp., etc.

Parthenocarpy

In some cases of angiosperms, the ovary normally develops into a fruit without pollination and fertilization. This type of free development of fruit is known as parthenocarpy. Such parthenocarpic fruits are always seedless. Sometimes the fruit formation may be induced by artificial pollination by foreign pollen from another species but without subsequent fertilization. The parthenocarpy may also be induced by the spraying of growth-promoting substances such as NAA. This is called induced parthenocarpy. The examples of parthenocarpy are commonly found in banana, guava, grapes, pineapple, papaw, *Thalictrum*, *Alchemilla*, etc.

Polyembryony

Polyembryony means the occurrence of more than one embryo in a seed. Polyembryony was discovered first by Leeuwenhoek (1719) and was later confirmed by Schnarf (1929). There are two types of polyembryony, such as false and true polyembryony. In true polyembryony, more than one embryo is formed in the same embryo sac of the ovule. On the other hand, in false polyembryony, more than one embryo arises in different embryo sacs in the ovule. According to Gustafsson (1946), false polyembryony should be restricted to those cases "in which two or more nuclei, each with its own embryo sac, fuse at an early stage." All others are grouped under true polyembryony. In angiosperms, polyembryony may be of several types, such as:

(a) **Cleavage polyembryony:** This is the simplest method where an increase in the number of embryos takes place as a result of cleavage of the zygote or proembryo into two or more units. Polyembryony is quite common in gymnosperms. It is common in orchids, e.g., in *Eulophia epidendran*, *Vanda* sp. The other examples of cleavage polyembryony are met within *Nymphaea advena*, *Empetrum nigrum*, *Nicotiana rustica*, etc.

(b) **Origin of embryos from cells of the embryo sac other than the egg.**

(c) **Origin of embryo from cells outside the embryo sac.**

(d) **Origin of embryos from other embryo sacs in the ovule.**

14. 5 Summary

It is clearly understood from this study how embryo is formed by asexual method instead of normal fertilization process i.e., apomixis. Knowledge regarding the polyembryony in relation to true and false polyembryony can be gathered. Moreover, how cleavage polyembryony is formed that can also be understood.

14. 6 Questions

1. Write notes on:

   (a) Polyembryony (b)Apomixis
2. State the differences between false and true polyembryony.
3. Describe different types of apomixis you have studied.

14. 7 Answers

1. See article no.14.4 & 14.2
2. See article no. 14.4
3. See article no. 14.2

FurtherReadings

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