

মানুষের জ্ঞান ও ভাবকে বইয়ের মধ্যে সঞ্চিত করিবার যে একটা প্রচুর সুবিধা আছে, সে কথা কেহই অস্বীকার করিতে পারে না। কিন্তু সেই সুবিধার দ্বারা মনের স্বাভাবিক শক্তিকে একেবারে আচ্ছন্ন করিয়া ফেলিলে বুদ্ধিকে বাবু করিয়া তোলা হয়।

— রবীন্দ্রনাথ ঠাকুর

"Any system of education which ignores Indian conditions, requirements, history and sociology is too unscientific to commend itself to any rational support".

— Subhas Chandra Bose

ভারতের একটা mission আছে, একটা গৌরবময় ভবিষ্যৎ আছে, সেই ভবিষ্যৎ ভারতের উত্তরাধিকারী আমরাই। নূতন ভারতের মুক্তির ইতিহাস আমরাই রচনা করছি এবং করব। এই বিশ্বাস আছে বলেই আমরা সব দুঃখ কষ্ট সহ্য করতে পারি, অন্ধকারময় বর্তমানকে অগ্রাহ্য করতে পারি, বাস্তবের নির্ভর সত্যগুলি আদর্শের কঠিন আঘাতে ধুলিসাৎ করতে পারি।

— সুভাষচন্দ্র বসু

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BOTANY [HBT]

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GE - BT - 31



NETAJI SUBHAS OPEN UNIVERSITY

Under Graduate Degree Programme
Choice Based Credit System (CBCS)

SELF LEARNING MATERIAL

BOTANY
[HBT]

Plant Anatomy and Embryology

GE-BT-31

PREFACE

In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. *core, generic, discipline specific elective, ability and skill enhancement* for graduate students of all programmes at Honours level. This brings in the semester pattern which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade “A”.

UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme.

Self Learning Material (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs.

I wish the venture a grand success.

Professor (Dr.) Subha Sankar Sarkar
Vice-Chancellor

Netaji Subhas Open University
Under Graduate Degree Programme
Choice Based Credit System (CBCS)
Subject : Honours in Botany (HBT)
Course : Plant Anatomy and Embryology
Course Code : GE-BT-31

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**NETAJI SUBHAS
OPEN UNIVERSITY**

**UG : Botany
(HBT)**

Course : Plant Anatomy and Embryology

Course Code : GE-BT-31

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Unit 1 □ Meristematic and Permanent Tissues

Structure

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1.0 Objective

From this unit study a complete idea related to meristematic and permanent tissue can easily be understood. Knowledge regarding shoot and root apical meristem alongwith the categorization of meristematic tissue and permanent tissues are achieved. More over the nature and function of various simple as well as complex tissues can also be ascertained.

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 usually situated at the apices of roots or stems. Here all the cells are alike. Promeristem 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'. 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 occur 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, 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 eg. interfascicular cambium.

D. Meristem based on function :

- (i) **Protoderm or future epidermis** : It is the outer most layer of meristematic cells which forms epidermis.
- (ii) **Procambium or provascular tissues** : This is the tissue of elongated cell which 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, and form 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, cortex are the 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 leaf blade uniseriate epidermis, etc.
- (iii) **Rib meristem** : Cell of this meristem divides only in one plane and thus columns or rows of cells are produced. Increase in length of the organ is concerned are takes place by this meristem. The formation of pith and cortex of young roots and stems are the examples of this meristem etc 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 root apical meristem. Cells of 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. Root apex is simpler, producing no lateral organ at the tip. It is subterminal in position covered by more vacuolated cells of root cap. Organisation of root apical meristem is more or less uniform due to absence of lateral organs.

The tissues of the mature root are eventually derived from the group of cells, which comprise the apical meristem of primary root. Apical meristem of root produces

cells not only towards the axis but also away from it, which initiate root cap and due to presence of 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 absence of nodes and internodes, the root grows more uniformly in length than the shoot.

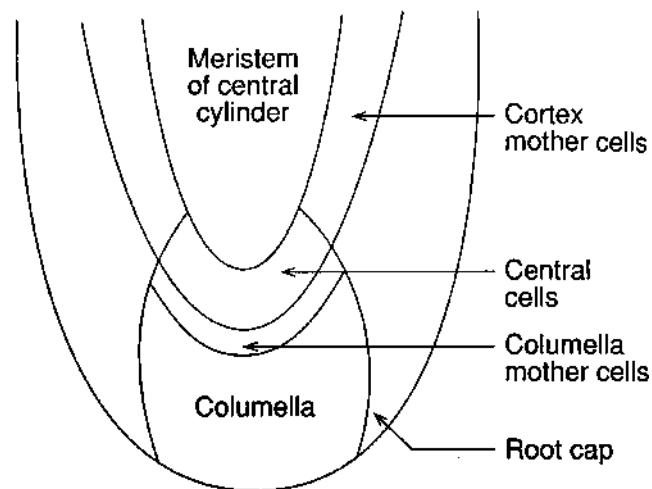


Fig. 1 : Diagrammatic representation of the root apical meristem showing different zones. (Redrawn after Mauseth, 1988)

1.3.1 Description of root apical zones (Fig. 1)

- A. Apical cell theory :** This theory was developed by Nageli (1878). In *Dryopteris* there is a single apical cell and from which all the cells of root apical cell derived.
- B. Histogen Theory :** Hanstein (1868) proposed histogen theory and 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 layer, known as histogens. Hanstein opined that histogens arise from separate sets of initial and give rise to dermatogen, periblem and plenome.
- (i) Dermatogen is the outermost uniseriate layer. Cells of this zine generally divide by radial walls and give rise to epidermis. In few cases the cells of this layer

divide by tangential as well as radial walls give rise to multiple epidermis as in *Ficus* leaf.

- (ii) Periblem is lying between the dermatogen and plerome. This zone is constituted with isodiametric cells. Cells of this zone divide actively and give rise to primary cortex. 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 pith and vascular cylinder.

The terms dermatogen, periblem and plerome, as used today have a somewhat different meaning from those as used by Hanstein. Fahn (1967) suggested to use 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.

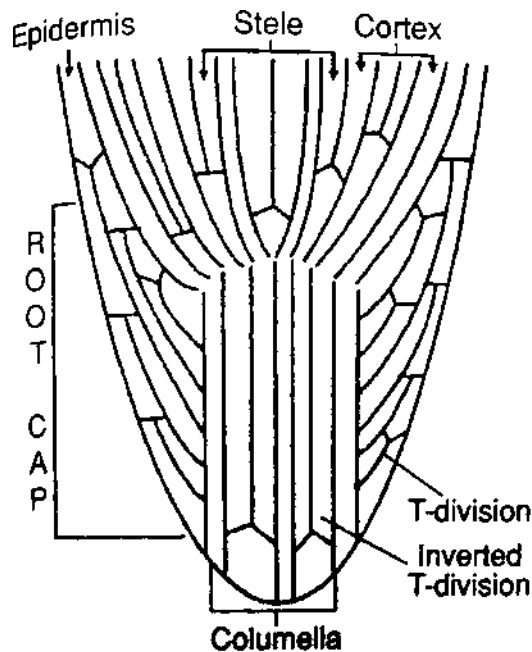


Fig. 2 : Diagrammatic representation showing the root apex meristem according to the Körper-Kappe theory

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

1.3.3 Körper-Kappe theory (Fig. 2)

This theory was proposed by Schüpp (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 says that the cells in the root apex divide in a pattern called 'T'-divisions. Cells of 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. Region of the apex is the Körper. In this inner region 'T' is inverted (\perp) 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 has been observed by Clowes (1958 & 1976) that a group of cells between the root cap and active meristematic zone in the root apex of *Zea mays* is present. These groups of cells appear in the shape of a hemisphere on a disc, and these cells have a 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 promeristems. Through various techniques, the existence of a quiescent centre has now been demonstrated in the root apices of a considerable number of species. According to Clowes (1958, 1976) a quiescent centre develops during the ontogeny of a 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., a quiescent centre in the roots of *Zea* where the cytoplasm had a lower content of

RNA and the cells have 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 the region have a lower concentration of DNA, RNA and protein than any other cells in the root apex. According to Clowes the cells of 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 quiescent centre divide during certain periods, specially during the formation of secondary roots or after the root has been damaged. Cells below the quiescent centre are active and give rise to root cap.

1.5 Promeristem

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

1.6 Shoot Apical Meristem

The shoot apex proper is considered as the terminal part of the shoot which is situated immediately above the uppermost leaf primordium. The growing region of the terminal bud, all primary tissues are derived from this produced lateral organs like leaf and bud primordia and that is why its development is dependent on these lateral outgrowth.

Leaf primordia produce in a particular pattern and sequence below the shoot apex, and it is here that many structural characters of the plant seem to be determined. Time and space interval between the initiation of two successive primordia is termed as plastochron and within one plastochron the size and shape of the apical zone change. The rate of cell division and other biochemical activities also change considerably at this stage. The periodic changes in the meristem can be seen best in opposite leaved forms.

Like root apex, shoot apices are also been described in different theories and those are stated below (Fig. 3) :

- (1) **Apical cell theory** : According to Nägeli (1878) a single tetrahedral apical cell of shoot apex produces other cell. (as seen in) Cryptogams
- (2) **Histogen theory** : This was introduced in 1870 by Hanstein who considered that the primordial meristem is sharply separable into three distinct zones or histogens. According to this theory the apical meristem or growing region of the stem is composed of small mass of cells which are all alike and the cells are in a state of division. These meristematic cells constitute promeristem. The cells of promeristem soon differentiate into three regions—dermatogen, periblem and plerome. Every zone consists of a group of initials and is termed as histogen or a tissue builder.
 - A) **Dermatogen** : This is the single outermost layer of the cells which later gives rise to the epidermis of the stem.
 - B) **Periblem** : This region is found internal to the dermatogen, and is the middle region of the apical meristem. It is single layered at the apex but in central part it becomes multilayered. It develops into the cortex.
 - C) **Plerome** : This is found internal to the periblem and it is the central meristematic region of the stem apex. Cells of plerome zone 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 put forwarded by Schimidt (1924). According to this theory there are two zones of tissues in the apical meristem termed as tunica and corpus. Tunica consists of peripheral layers of cells divide anticlinally and corpus consists of central cells in which division occurs in all planes. But in gymnosperms except Gnetales there is no surface layers dividing antilinally. Thus so many workers have raised objection.

The Tunica-Corpus theory served well in the establishment of meristematic pattern of shoot apices of seed plants. The position, number and behaviour of the initiating cells in seed-plant stems, and early stages in the development of primary body of the shoot are now better understood. The lateral organs of the

stem *i.e.*, leaves, branches and floral organs, arise near the apex and studies of tunica and corpus have added greatly to a knowledge of origin and early development of these organs.

- (4) **Cytohystological zonation** : Popham (1951) describe 7 types of shoot apices on the basis of cytohystological studies on reaction to different stains.

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

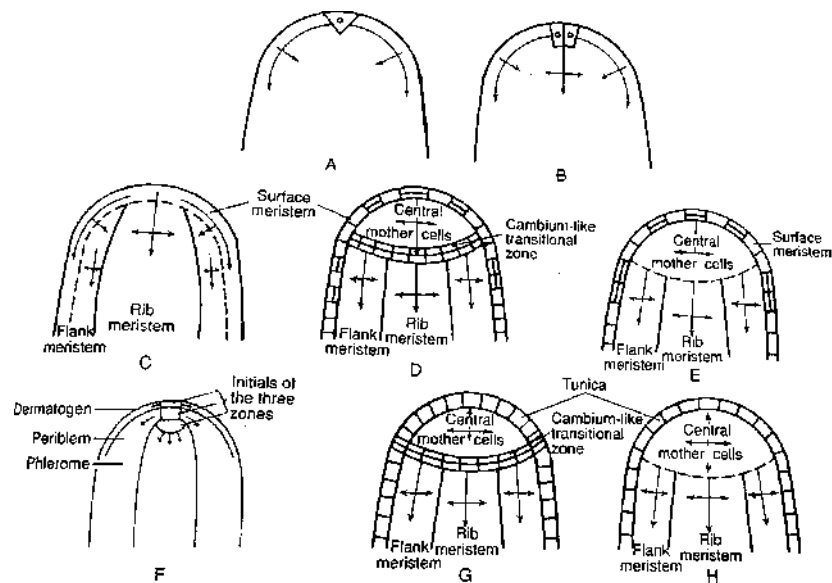


Fig. 3 : Diagrammatic representation of the shoot apices showing the histological zonations : A. Single apical cell in pteridophyte. B. *Selaginella* type with – 5 apical initials. C. *Cycas* type. D. *Ginkgo* type. E. *Cryptomeria-Abies* type. F. Diagram showing the histogen concept in angiosperm shoot apex. G. *Opuntia* 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 receptacular 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 foliage 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 strained form 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 use temporary initial cells. He termed them as 'continuing meristematic residue' (C.M.R.). Newman classified vegetative shoots 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 initials 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 inner layer or outer layer may divide more than one plane.

1.7 Simple and Complex tissues

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 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 vacuole.

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

1.7.1 Simple tissues

Simple tissues consist of single type of more or less uniform cells performing similar function and thus homogenous 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 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 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 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 known as chlorenchyma. Sometimes 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.

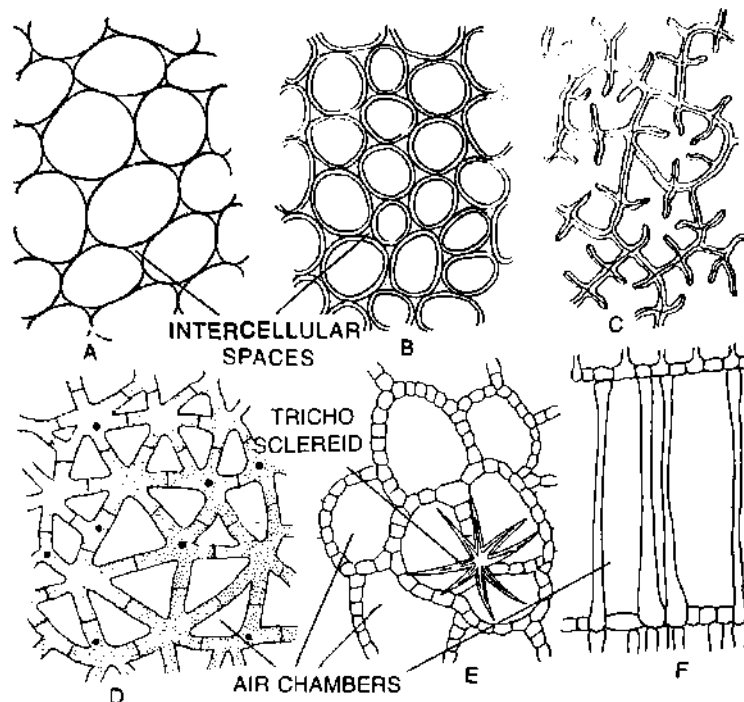


Fig. 4 : Parenchyma tissue. A—Thin-walled parenchyma. B—Thick-walled parenchyma. C—Parenchyma in the mesophyll of *Pinus* needle. D-F—Different forms of aerenchyma: E—Petiole of *Musa* sp. Petiole of *Nymphaea* sp. F—Stem of *Jussiaea* sp.

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 carryout 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 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 usually regarded as form of parenchyma specislized 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 thickwalled type of parenchyma

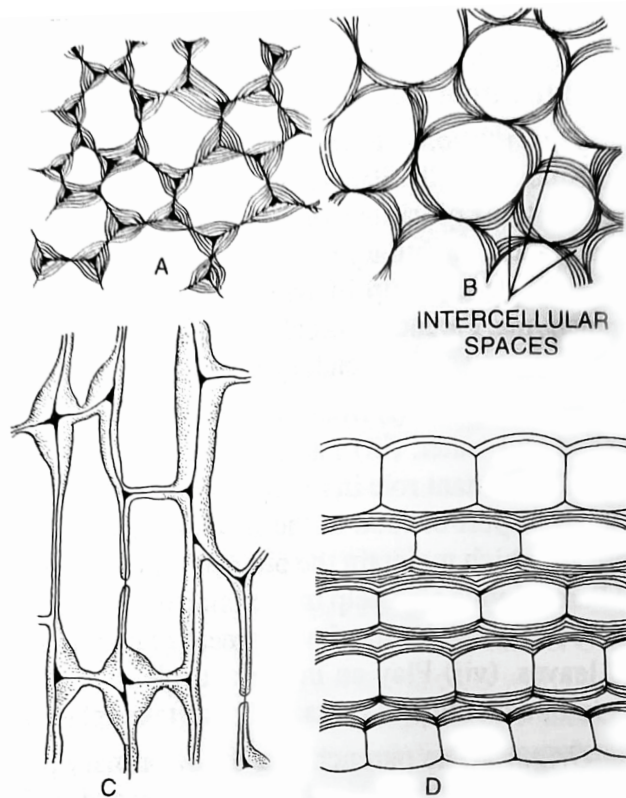


Fig. 5 : Different forms of collenchyma.

A—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 lacunar 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 than on the radial walls of the cells.

Example : Stems of the species of *Sambucus*, *Rhamnus*, etc.

3. **Sclerenchyma** : The sclerenchyma consists of thickwalled cells, often lignified, whose main function is mechanical (Fig. 6). This is supporting tissue that withstands various strains which resulted 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.

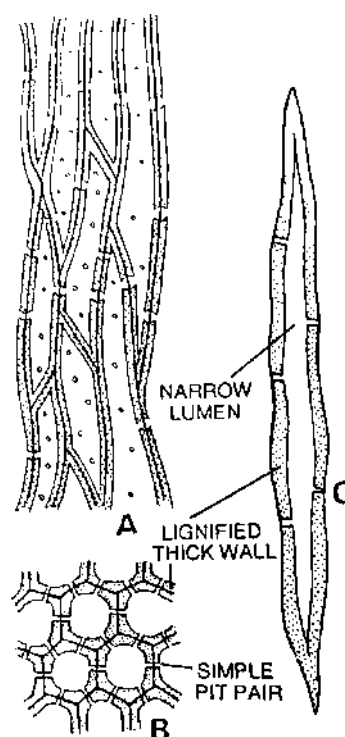


Fig. 6 : Sclerenchyma. A, L.S. of fibres; B, T.S. of fibre; C, a single fibre as seen in longitudinal section.

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 kind 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 fibre look angular. In some case 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.

1.7.2 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 they usually longer than trachea of the plant in which they occur. These fibres are narrow with highly thickened secondary walls and reduced simple pits. Libriform fibres have 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 present in *Vitis*, *Zingiber*, etc.

1.7.3 Extraxylary fibres

These type 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, extra xylary 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 vary thick and some have lignified walls, others are non-lignified. All these fibres are with 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.

Fibers give mechanical strength and rigidity to the plant body and help to withstand strains and stresses.

Fibers develop from different meristems such as procambium, cambium, ground meristem and also from protoderm.

1.7.4 Sclereids or Sclerotic cells

Sclereids are isodiametric i.e. polyhedral in shape and non-parenchymatous cells, columnar, or more or less profusely branched i.e. (Fig. 7 and 8), irregular. These are much shorter than true fibres. Sclereids are thick-walled but the thickness of the walls is not uniform. Sclereid may have 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 as of their hard walls.

Sclereids are abundantly present in cortex, phloem, pith and mesophyll tissue as idioblasts or cell-cluster in pericarp of fruit such as *Pyrus*, *Psidium*, etc. and in thick testa of the seeds.

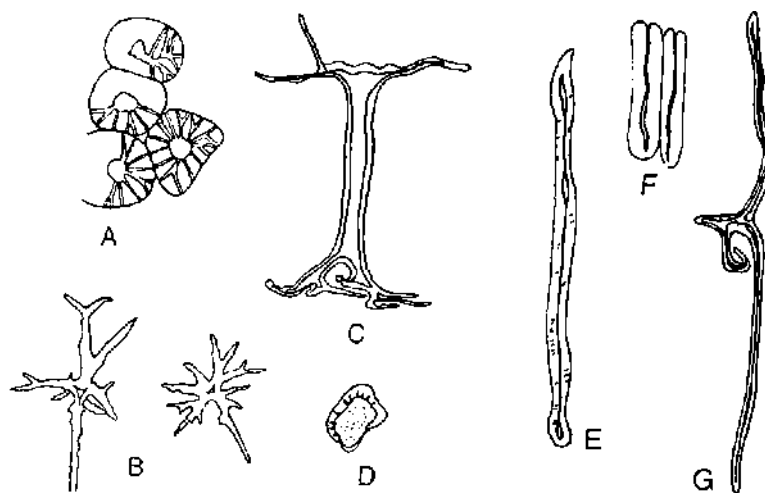


Fig. 7 : Different forms of sclereids. A—Brachysclereids from the pulp of *Pyrus* fruit. B—Astrosclereids from the leaf of *Trochodendron*. C—Osteosclereid from the leaf of *Hakea*. D—Brachysclereid with uneven wall thickening from the cortex of *Cinnamomum* stem. E—Macrosclereid from the pulp of apple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

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

- (a) **Brachysclereids or stone cells :** These sclereids are a like 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 rodlike 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 inter cellular spaces of *Nymphaea* sp.

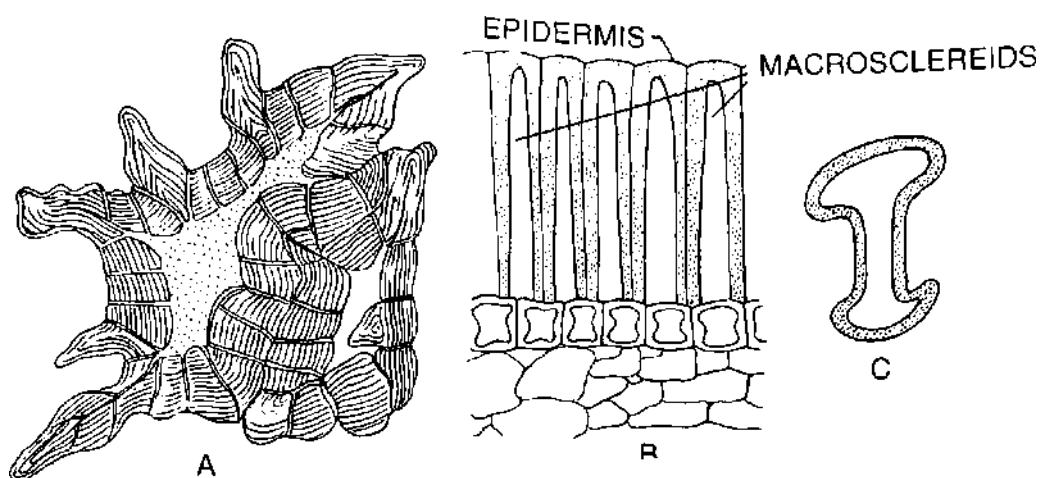


Fig. 8 : Sclereids. A—Irregular sclereids from *Tsuga* sp. B—Macrosclereids from testa of *Phaseolus* seed. C—Osteosclereid from testa of *Pisum* seed.

(e) **Trichosclereids :** These are very much elongated sclereids.

Examples : In aerial roots of *Monstera* sp. 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.

1.8 Complex Tissues

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

1.8.1 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.

1.8.2 Tracheids

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

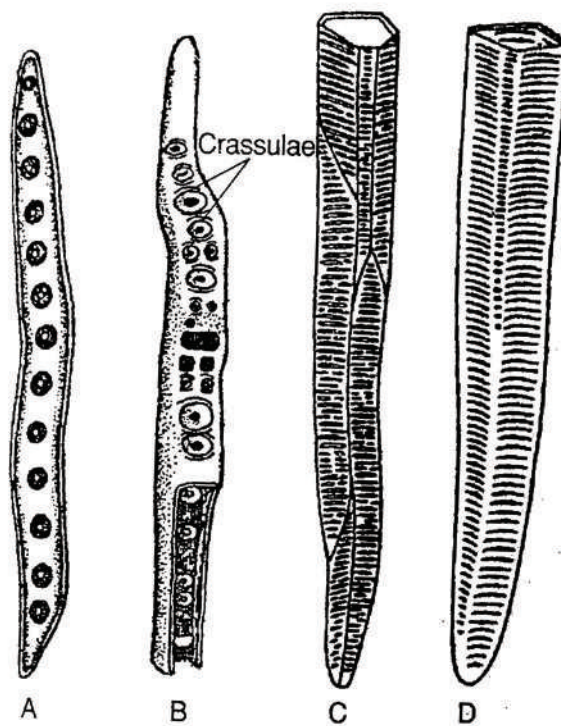


Fig. 9 : Tracheids : A. Bordered pitted tracheid.
 B. Bordered pits with crassulae on a portion of a tracheid.
 C & D. Parts of tracheids with scalariform thickening

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. Tracheid, also have various types of thickening such as annular, spiral, scalariform, reticulate, Pitted, etc. The tracheids are specially adapted to the function of conduction. Due to their firm and rigid walls they also give mechanical support for plant body.

1.8.3 Fibres and fibre-tracheid

Fibres and fibre-tracheids are developed from tracheid due to decrease on length of tracheid 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 fibre and normal tracheids there are many transitional forms which may be neither termed as typical fibres nor 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 as for example formed 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 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 nucleus

1.8.4 Vessels

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 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 which water is being conducted from

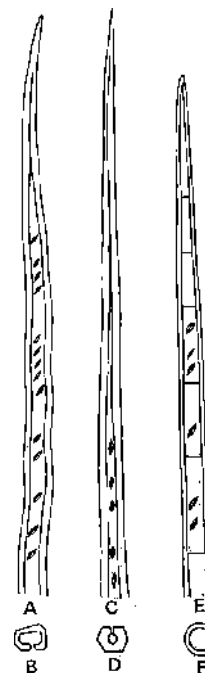


Fig. 10 :

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 mahagoni*, (After Eames and Mac Daniels, 1974)

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 bears 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, in many monocotyledons except *Yucca*, *Dracaena* lack vessel elements.

1.8.5 Wood fibres

Wood fibres consists of long, narrow, thick-walled, lignified cells. Fibres remain associated in xylem with other elements. Two major types of xylem fibres are recognised eg. 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 trachea. Libriform fibres are narrow with thick secondary wall 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.

1.9 Phloem

This complex tissue is a constituent of the vascular tissues of plant. The xylem and phloem have evolved along more or less in 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 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 cell 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

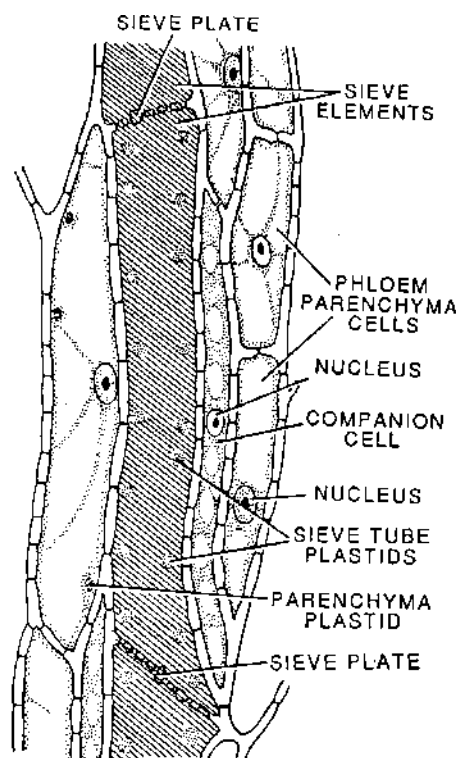


Fig. 11 : Phloem tissue from the stem of *Nicotiana*.

1.9.1 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 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 become 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.

Important property of the sieve element protoplast of dicotyledons is the presence of 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.

1.9.2 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 nuclei of the companion cells serve for the nuclei of

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 other 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.

1.9.3 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 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.

1.9.4 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.

1.10 Summary

From the discussion it can be concluded that the knowledge of both meristematic and permanent tissues as well as the simple and complex 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. Group of masses of the cells that are alike in origin, structure, and function form tissues. The plant body consists of vegetative tissues and reproductive tissue. In the higher group of plants, the plant body is somewhat more complex in its cellular structure. The cells differ very much in their kind, form and origin in higher plants. Detail knowledge of simple and complex 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.

1.11 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 dynamic aspect of shoot apex.
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.

1.12 Answers

1. See article no. 1.2
2. See article no. 1.3
3. See article no. 1.6
4. See article no. 1.7
5. See article no. 1.8
6. See article no. 1.9

Unit 2 □ Organs

Structure

2.0 Objective

2.1 Introduction

2.2 Primary structure of a typical dicotyledonous root

2.3 Primary structure of a typical monocotyledonous root

2.4 Primary structure of a typical dicotyledonous stem

2.5 Typical primary anatomical structure of monocotyledonous 2.6 Anatomical structure of a typical dicotyledonous leafstem

2.6 Anatomical structure of a typical dicotyledonous leaf

2.7 Anatomical structure of a typical monocotyledonous leaf

2.8 Summary

2.9 Questions

2.10 Answers

2.1 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 bundles varies from two to six in dicotyledonous root and are numerous *i.e.*, 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 *i.e.*, 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 closed in stems while these bundles are radial in roots. Moreover, the arrangement of xylem within vascular bundle where endarch, exarch or mesarch is 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).

2.0 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 continuous 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.

2.2 Primary structure of a typical dicotyledonous root

Transverse section of a typical 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 also known as 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 with in them. In the roots of dicotyledons which possess secondary growth and shed their cortex early, the cortex consists mainly of parenchyma. In the aquatic plants the intercellular spaces are large and form distinct air spaces. The cortex of roots is usually devoid of chlorophyll. Exception are in the roots of some aquatic plants and aerial roots of many epiphytes like *Tinospora* spp. Various idioblasts and secretory structures are found in the cortex root 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 with in 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 shown 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 dicotyledons plants have few xylem strands. The tap root 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.

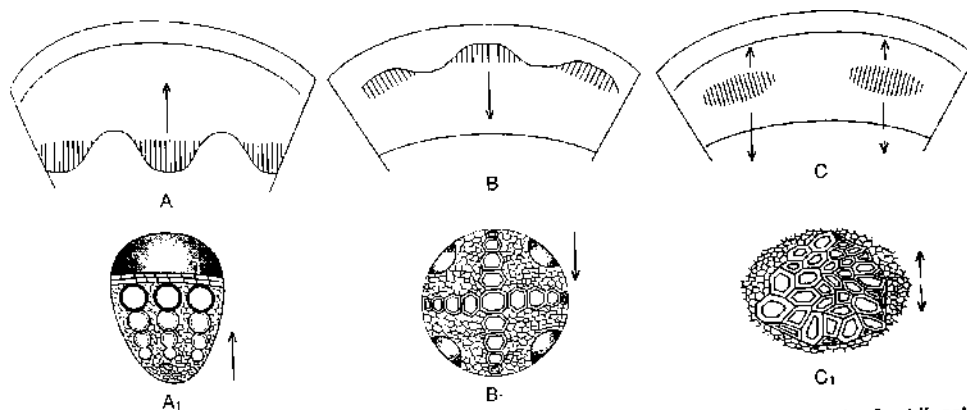


Fig. 12 : Diagrams showing order of development of primary vascular tissues in cross-section : A & A₁. Centrifugal development with endarch xylem. B & B₁. Centripetal development with exarch xylem. C & C₁. Both centripetal and centrifugal development with mesarch xylem

2.3 Primary structure of a typical 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 inter cellular 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 present 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 the part of primary cell wall. The strip 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. The 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 the monocotyledons the pericycle often undergoes sclerification in older roots, partly or entirely. The pericycle 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 large pith which may be parenchymatous or sclerenchymatous. Bundles are numerous and referred to as polyarch.

The xylem is exarch, *i.e.*, the protoxylem lies towards periphery and the metaxylem towards the centre. The vessels of protoxylem are narrow and the walls have annular and spiral thickenings whereas that of metaxylem the vessels are broad and they 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*.

2.4 Primary structure of a typical dicotyledonous stem

Transverse section of young stem shows three well defined zones or tissue system such as 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 chloroplast. Epidermis serves mainly for restricting the rate of transpiration and for protecting 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 contain 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 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 in 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 tissues. Sometimes chloroplast containing collenchyma cells of stems carryout 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. Cells when exposed to light they often develop chloroplasts and are known as chlorenchyma. These chlorenchyma cells perform photosynthesis. Parenchyma cells plays 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 act 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 endoermis 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 ring. Each bundle is composed of phloem, xylem and cambium (Fig. 13).

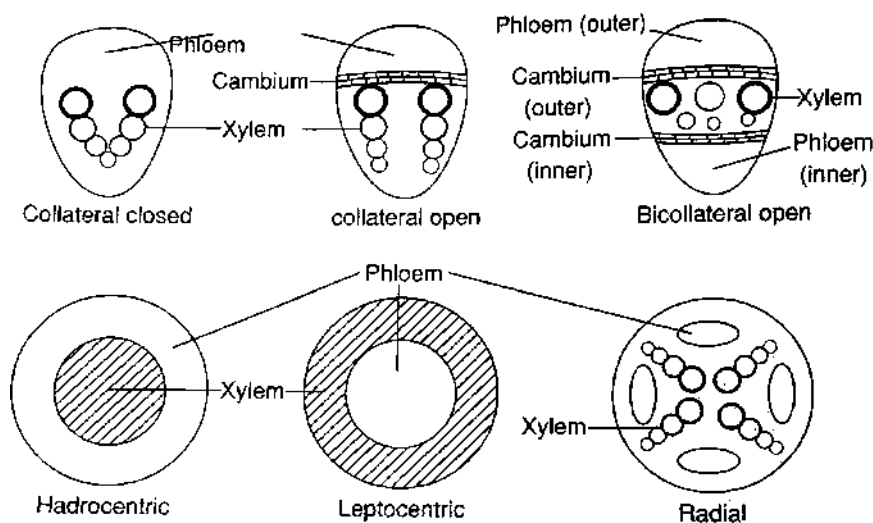


Fig. 13 : Diagrammatic drawing showing different types of vascular bundles

- (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. 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 having with parenchyma are 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 is size. Cambium by division gives rise to xylem towards the centre of the stem 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 stem and for the storage of food.

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

2.5 Typical primary anatomical structure of monocotyledonous stem

The monocotyledonous stem 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).

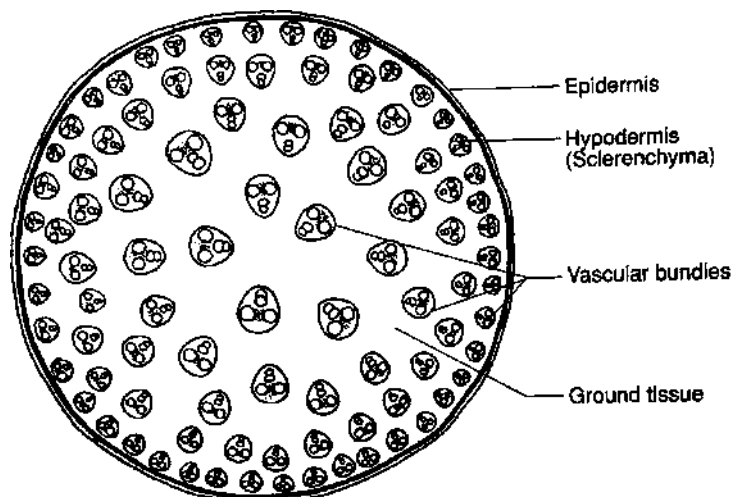


Fig. 14 : Diagrammatic view of the transverse section of a young maize stem

Typical structural compositions or arrangements are as follows :

Epidermis : The epidermis consists of 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 thick cuticle. The epidermal hairs are altogether absent. Stomata present in *Triticum aestivum* stem.

Hypodermis : Below the epidermis, usually two or three layers of sclerenchymatous hypodermis 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 layer of chloroplast containing parenchyma are found. These may be termed as cortex. The innermost layer of the cortex consists of compact cells and 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 small cortical region. Cortical cells are polygonal and large. Immediately below the cortex, a single layered 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 sclerenchymatous bundle sheath. The bundle consists of xylem and phloem.

Usually the xylem is ‘Y’-shaped and consists of pitted and bigger vessel 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 breaking down of the inner protoplasm vessel.

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

2.6 Anatomical structure of a typical dicotyledonous leaf

The leaf dicotyledons is usually bifacial and dorsiventral. This 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

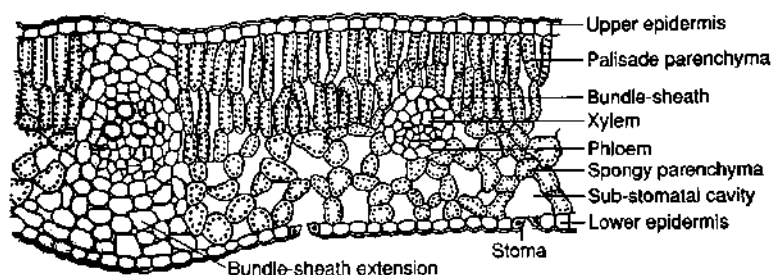


Fig. 15a : Transverse section of a portion of a mango leaf

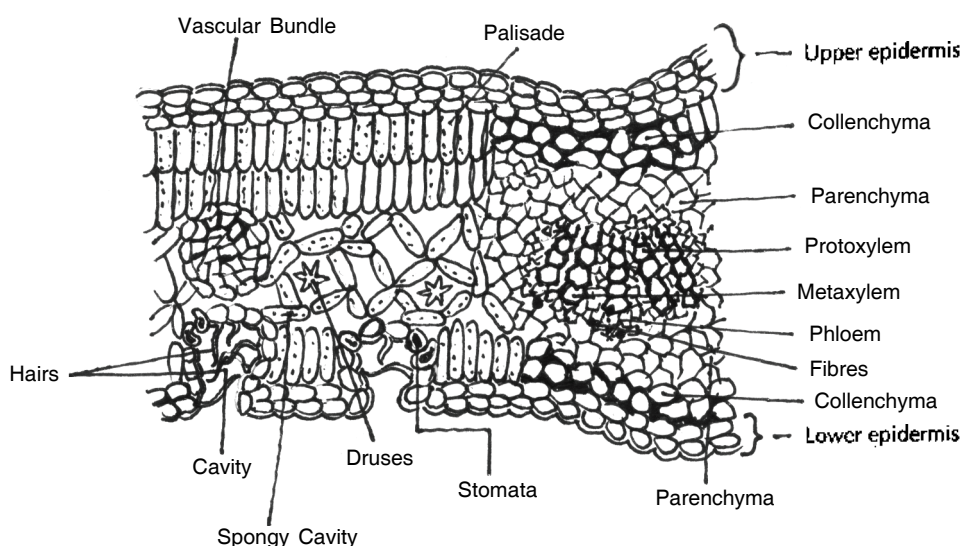


Fig. 15b : Transverse sectional view of dorsiventral leaf with cellular development and composition.

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 leaf. Usually upper surface lack stomata but the lower surface of leaf contains stomata. Number of stomata in the lower epidermis of 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 the depressions.

Usually the stomata are meant for exchange of gases in between the plant and the atmosphere. The transpiration takes place through the stomata and the surplus water is being 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 in between the palisade and spongy cells. The cells of palisade tissues 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 large number of chloroplasts. These cells are photosynthetic in nature. The spongy tissue is made up of many layers of cells. Less concentration of chloroplasts are 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 mid rib, 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 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 presence of large air spaces in the spongy tissue they are more adaptable to the exchange of gases between the cells and atmosphere.

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

The tissues which constitute the conducting system are situated near the centre of midrib. This system may have various shapes e.g., the form of a ring, a crescent shaped ring, a crescent arc, 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 lower surface.

Xylem is composed of various kind of vessels, tracheids, wood fibres and wood parenchyma. Specially 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 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 bundle sheath are enclosed by sclerenchyma in the members of Winteraceae, Melastomaceae, etc.

2.7 Analomical structure of a typical monocotyledonous leaf

The monocotyledons as a group shows greater diversity of specialized leaf type. In general monocotyledonous leaves are parallel veined.

Most of monocotyledonous leaves are nearly erect and both surfaces usually receive direct and equal amount 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 sides 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 upper and lower surfaces of the leaf. The epidermal layers are uniseriate and composed of more or less oval cells. The

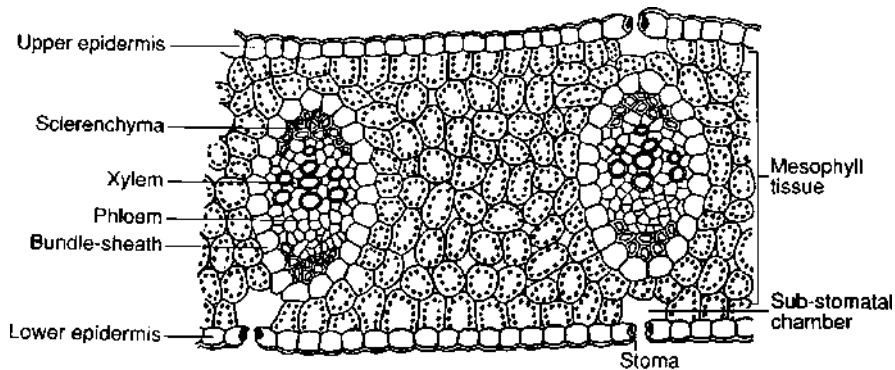


Fig. 16 : Transverse section of a portion of a *Polianthes* (tuberose) leaf

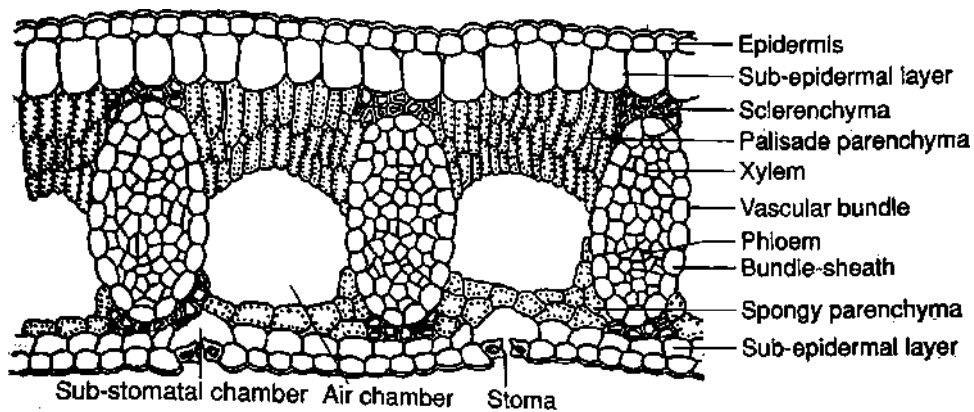


Fig. 17 : Transverse section of a portion of a *Musa* leaf

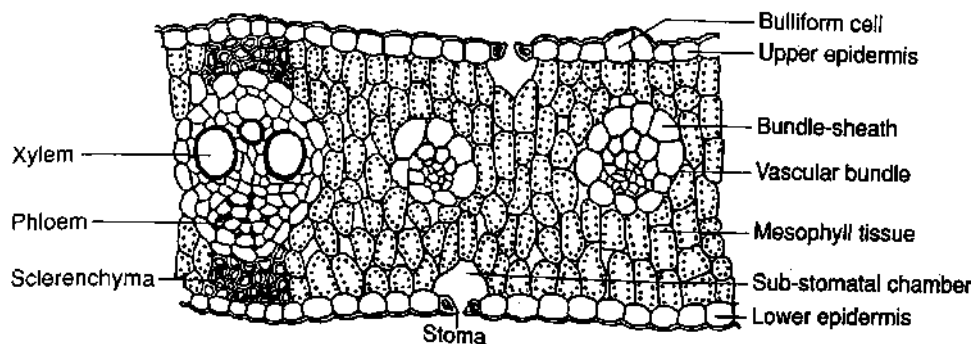


Fig. 18 : Transverse section of a portion of a *Zea* (maize) leaf

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 presence of 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 upper side and phloem towards lower side in the bundles. Usually each bundle remain 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 the ends of the large vascular bundles which give mechanical support to the leaf.

2.8 Summary

The study of the distinctive anatomical characters of both the dicotyledonous and monocotyledonous root can easily be used to understand the relation of xylem, nature of pith, pericycle, etc.

In case of dicotyledonous stem vascular bundles remain in a ring like manner. On the other hand in case of monocotyledonous stem vascular bundles remain scattered within the ground tissue of the stem. In case of dicotyledonous stem vascular bundles are conjoint, colateral and open. Xylem is endarch. In monocotyledonous stem vascular bundles remain scattered within the ground tissue. Vascular bundles are co-lateral and closed. Xylem is endarch.

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

2.9 Questions

1. Draw and describe the anatomical structure of dicot root as seen under transverse section.
2. With suitable drawing and labelling describe the structure of 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 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 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 internal structure of dorsiventral leaf.
8. With labelled diagram describe the internal structure of a typical monocotyledonous leaf as found in transverse section.
9. Distinguish 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.

2.10 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 3 □ Secondary Growth

Structure

3.0 Objective

3.1 Introduction

3.2 Structure and function of Vascular Cambium

3.3 Seasonal activity of vascular cambium

3.3.1 Important natural activity of cambium

3.4 Secondary growth in roots and stems

3.4.1 Secondary growth in dicotyledonous roots

3.5 Secondary growth in dicotyledonous stem

3.5.1 Intrastelar secondary growth in stem

3.5.2 Extrastelar secondary growth

3.5.3 Secondary growth in Monocot stem

3.6 Wood (Heart wood and sap wood)

3.7 Summary

3.8 Questions

3.9 Answers

3.0 Objective

Following are the different objectives achieved from the study of secondary growth :

1. Formation of cambium ring;
2. Formation of secondary xylem, secondary phloem and secondary medullary rays;
3. Structural features due to the seasonal activity of cambium with the change of season;
4. Formation of annual rings or growth rings;

5. Determination to calculate the age of a particular plant through the study of secondary growth.

Vascular Cambium : 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.

3.1 Introduction

The growth in thickness in the stems and roots of plants by the activity of cambium after the cessation of primary growth is termed as 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 extra stelar 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.

3.2 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 cell 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 vertical system of vascular cambium. The size of fusiform initials varies greatly, while the size of the ray initials is more or less uniform. The cells of cambium ring are either arranged in 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 so arranged that the ends of the cells in one tier remain more or less at the same level with another tier. This type is known as storied or stratified cambium. (ii) Much longer fusiform cells when ever do not occur in horizontal tiers and in which the fusiform initials partially overlapped with one another at the ends, this type is called as non-storied or non-stratified cambium (Fig. 19).

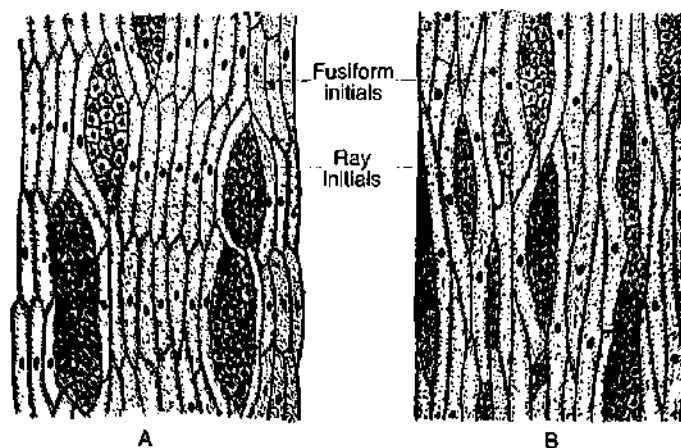


Fig. 19 : Fusiform initials and ray initials of cambium in longitudinal views : A. Storied cambium. B. Non-storied cambium

Cambium functions by dividing the cell tangentially and forms a new tier of cells. Cells produced by the cambial division, Cells at two tier and either the external layer matures into secondary phloem and 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 at cambium in between the secondary xylem and secondary phloem. The proportion of secondary xylem and phloem remains same through out 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 initial 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 both of 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. It helps in the establishment of connections in between the pith and cortex and helps in 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.

3.3 Seasonal activity of vascular cambium

The cambium remains active through out the entire life of plants those which are growing in tropical regions. Activity of cambium fluctuates with the fluctuation 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 this nature of vessels together form an annual ring and that represents one year growth. The age of a plant can roughly be determined by counting the total number of annual rings and this process of counting of age is known as dendrochronology. On the other hand from anatomical point of view, according to Fahn (1982), the activity of cambial cells takes place in two stages such as, (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 xylem is also possible due to the increase in 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.

3.3.1 Important natural activity of cambium

- (1) Cambium always produce secondary xylem towards inner side and secondary phloem towards out side.

- (2) It is always produced at a particular position. In a wounded stem new cambium is always formed at the beneath and parallel to the exposed surface and the new cambium completes the broken cylinder.
- (3) More or less homogenous cells of cambium produce a complex tissue having different types i.e., heterogeneous cells.
- (4) Activity of cambium is after 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** : Lower side of horizontal shoot of *Pinus* shows increased secondary growth and this increased secondary growth is due to gravity and this type of wood is known as reaction wood. It is developed on the leaning trunks or branches.
- (6) **Reaction to day length** : In plants like *Robinia* long day treatment produced all early wood with wide vessel members but short day treatment produced all late wood with a few narrow vessel members.
- (7) **Reaction to wood** : 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 is directed towards the 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 tension wood. Tension wood develops on the upper side of leaning dicotyledonous stems and similar to compression wood.
Tension woods are distinguishable as two types as (i) compact tension wood, in which the gelatinous fibres from continuous regions (e.g. *Acer*) and (ii) diffuse tension wood, in which single or groups of gelatinous fibres are scattered among the normal fibre (e.g. *Acacia*).
- (8) **Response to water** : According to Shephards *et al.* light moisture content cause more rapid cambial activity.

3.4 Secondary growth in roots and stems

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

3.4.1 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 so the secondary growth in roots is of special interest. The dicotyledonous roots possess as limited number of radial vascular bundles with exarch xylem. On the initiation of secondary growth, a few parenchyma cells beneath group of phloem become meristematic and thus as many cambial strips are formed as the number of phloem groups. Some of the cells of 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

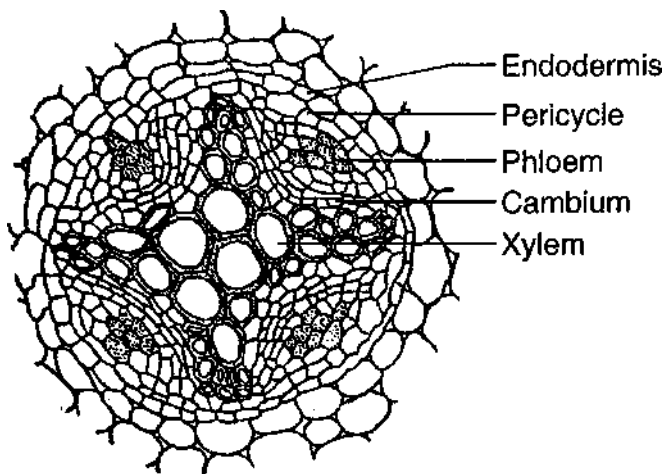


Fig. 20 : Early stages of secondary growth in a dicotyledonous root showing formation of the wavy cambium cylinder.

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 cell as rule cut more xylem cells than phloem cells. The first formed cambium produce secondary xylem much earlier and the wavy cambium ring ultimately becomes circular. Now whole of the cambium ring becomes actively meristematic and behaves in normal manner i.e. giving rise to secondary xylem on its inner side and secondary phloem on 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 the crushed condition. The cambial cells which originated from the pericycle lying against the groups of protoxylem functions 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 phellem towards 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).

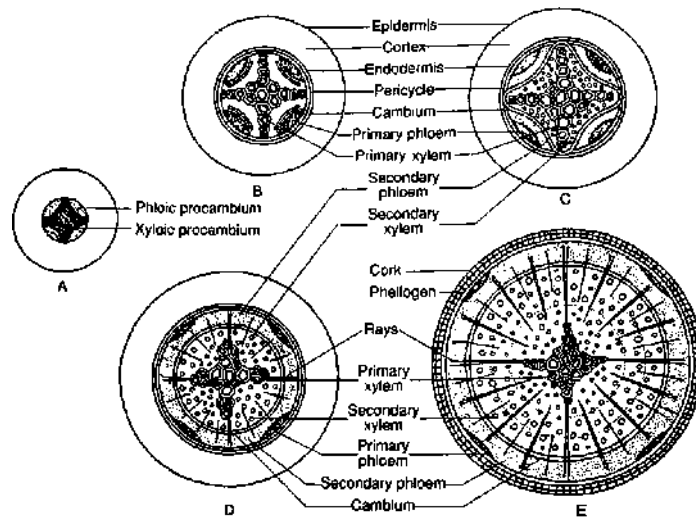


Fig. 21 : Diagrammatic view of the stages of secondary growth in thickness in dicotyledonous root

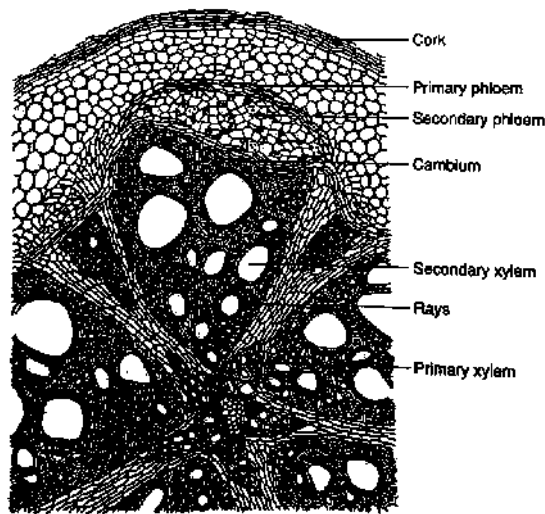


Fig. 22 : Cellular view of a portion of *Tinospora* root showing secondary growth in thickness

3.5 Secondary growth in dicotyledonous stem

The growth in thickness in stems and roots of plants by the activity of cambium after the ceasation 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.

3.5.1 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 ring the cambium of vascular bundle can be united laterally by the newly formed cambium strips to form a cambium ring.

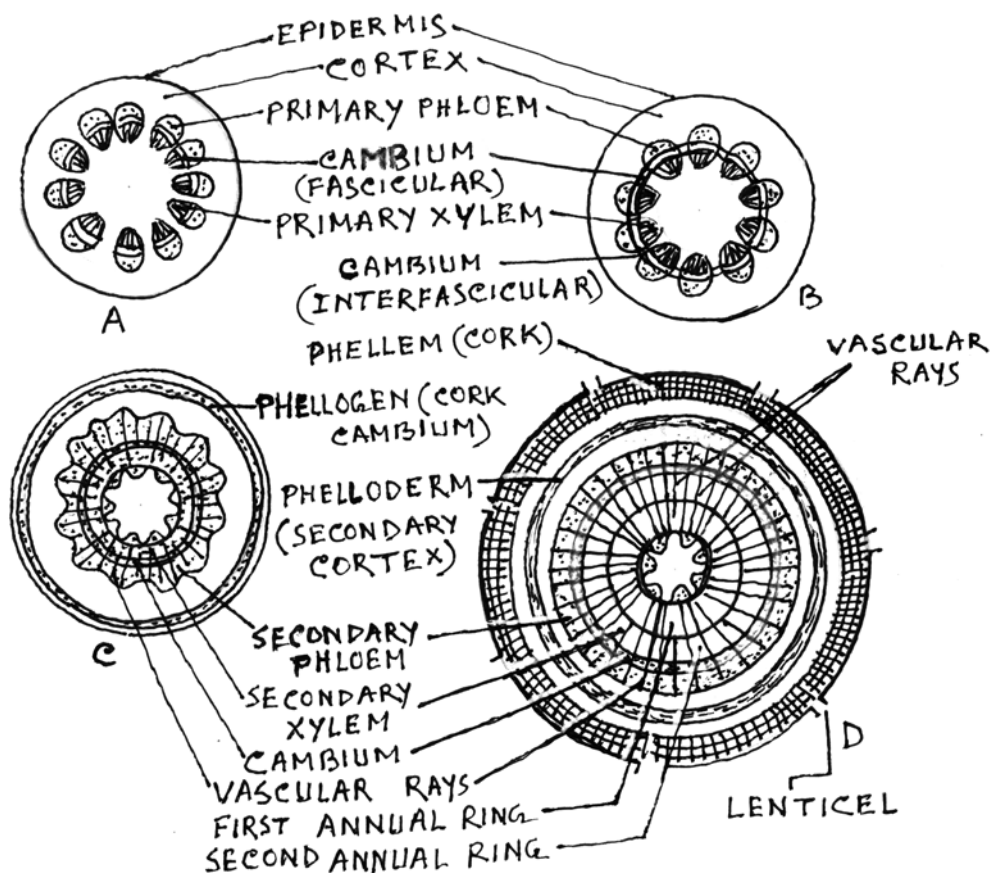


Fig. 23 : Secondary growth in thickness. A-D, diagrams showing stages in the secondary growth of a dicotyledonous stem.

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 divide repeatedly and periclinally to form tissues, both on 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 but crushed in the later stages. In this way a complete ring of xylem and phloem tissues are formed on inner and outer side of cambium ring respectively (Fig. 23).

Secondary xylem, which are produced by the activity of cambium possess four different kinds of elements viz. tracheids, vessels, xylem fibre and xylem parenchyma. Tracheids, vessels and xylem fibres are vertical system. Xylem parenchyma are of two types such as the vascular parenchyma which are vertical system and ray parenchyma which are in 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 xylems are pushed towards the centre and pith is crushed. Finally the central part of the stem is occupied by secondary wood. The primary phloems are pushed outward and may be crushed. The endodermis and pericycle disintegrate. Even the epidermis and some peripheral part of the cortex are ruptured.

The cambium, here and there, also produces short strips of radially elongated parenchymatous cells both on the inner and outer side 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. Cells help in the establishment of connection in between the pith and cortex and help in translocation of elaborated food matters.

Activity of 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 winters *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 as autumn wood or late wood. However, the line of demarcation is

quite conspicuous between the late wood of one year and early wood of 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 of age is dendrochronology.

3.5.2 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 stem are ruptured. This wound may expose the inner tissue to infection and dessication. To avoid this situation periderm formation takes place beneath this zone of tissue.

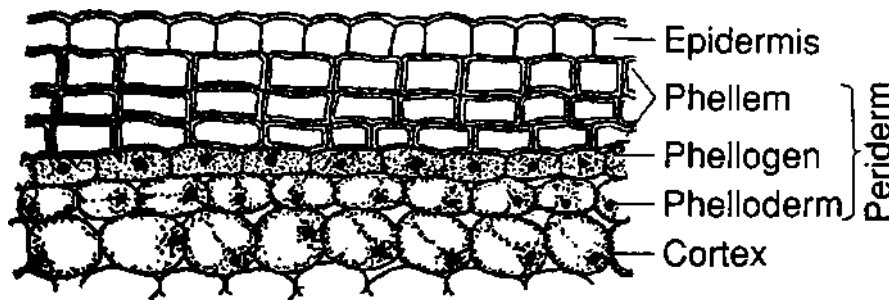


Fig. 24 : Diagram showing periderm formation

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 outside and a thin layer of phelloderm towards 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 fluid 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 subepidermal region or deep in the cortex, the living tissues outside it is devoid of supply of water and nutrition and as a result the tissue dies and dry 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 formed deeper and

deeper in the stem. Such successive and overlapping layers of cork form the rhytidome or shell bark or scale bark and detached 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 as 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 cell. This closing layer after breaks by extensive development of complementary tissues.

3.5.3 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 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 give rise to secondary leptocentric vascular bundles. These secondary vascular bundles remain embedded in a secondary conjunctive tissues (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 but storied cork cells, forming a protective tissue, are formed by the continuous periclinal division of peripheral cortical parenchyma cells and their suberization.

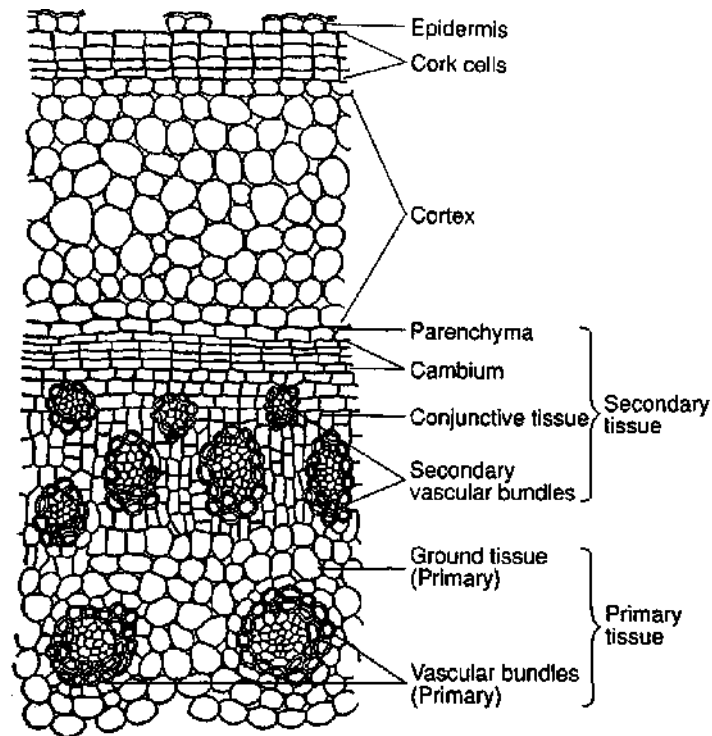


Fig. 25 : Cellular diagram of a portion of *Dracaena* stem in T.S. showing special type of secondary growth

3.6 Wood (Heart wood and sap wood)

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, darken in colour and is composed of dead xylem elements. This region is termed as heart wood. 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, composed of living parenchyma cells of the wood in addition to tracheary elements and fibres is known as sap wood. It is concerned with conduction of water and salt solutions from the root to the leaf. Moreover, it helps in storage of food and support (Fig. 23a).

Sap wood is gradually converted to heart wood. Conversion of heard wood from sap wood involves the following changes :

- (i) The loss of protoplast is in the living cells.

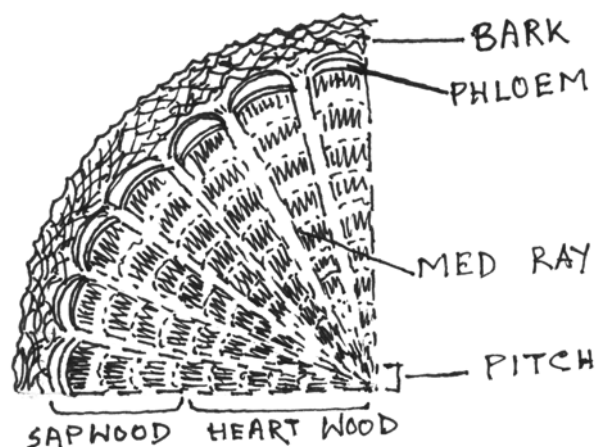


Fig. 23a : Transections of old dicot stems section showing heartwood and sapwood

- (ii) The cell sap is withdrawn and the water content of the cell wall is much reduced.
- (iii) Tylosis 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 cavity of the elements.

The quantitative relation between the amount of heart wood and sap wood 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 view point the heart wood is more durable and forms the timber of commerce.

3.7 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.

3.8 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.
 3. With suitable labelled diagram describe the secondary growth of a dicot stem.
 4. Write notes on the following :
 - (a) Extrastelar secondary growth in stem.
 - (b) Heart wood and sap wood.
-

3.9 Answers

1. See article no. 3.2
2. See article no. 3.3 & 3.3.1
3. See article no. 3.5
4. See article no. 3.5.1 & 3.6

Unit 4 □ Adaptive and Protective Systems

Structure

4.0 Objective

4.1 Introduction

4.2 Protective coverings of the plant body

4.2.1 Epidermis

4.2.2 Cuticle

4.2.3 Stomata

4.2.4 Types of stomata

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

4.2.6 Types of stomata based on ontogeny after Pant (1965)

4.3 General account of adaptation in xerophytes and hydrophytes

4.3.1 Introduction

4.3.2 Adaptive features of xerophytic plants

4.3.3 Adaptive features in hydrophytic plants

4.4 Summary

4.5 Questions

4.6 Answers

4.0 Objective

This unit gives us clear knowledge about the adaptive and protective systems of plants in relation to environmental conditions. Knowledge related to protective covering of the plant mainly epidermis, cuticle and stomata can be acquired. In addition to this adaptive nature of xerophytic and hydrophytic plants can also be ascertained.

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.

4.2 Protective coverings of the plant body

4.2.1 Epidermis

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

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

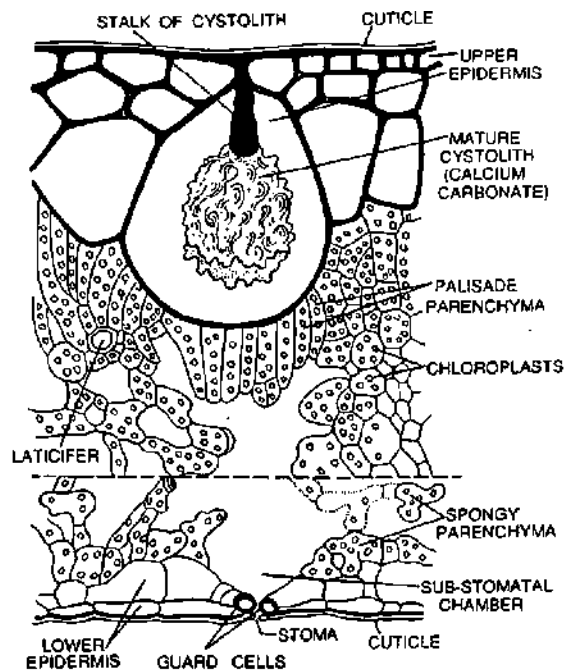


Fig. 26: Multi-cell-layered epidermis in T.S. of *Ficus elastica* leaf. A mature cystolith with calcium carbonate deposited on its stalk in the epidermal cell.

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. 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 the chloroplasts are also found. Sometimes, the substances like mucilage, tannin and calcium carbonate crystal *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 from loss of water.

On the surface of epidermis the outgrowths are present in form of hairs and trichomes which are uni-or multi-cellular. In case of roots the outermost layer is called as 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. Epidermis is primarily a covering layer which 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 thick cuticle, wax, hairs, etc. takes place.
3. It sometimes helps in photosynthesis and secretion.
4. The epidermis in many xerophytic plants act as the store house of water.
5. Few epidermal cells develop into the secretory tissues of nectaries, the stomata of leaves and stems, and the absorbing hairs of roots.

4.2.2 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 and 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 of 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 environment stresses.

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

4.2.3 Stomata

The stomata are minute pores which occur in the epidermis of the different 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 large 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 upper and lower surfaces of leaves, but specially they are confined to lower surface. In floating leaves stomata are confined only on 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 or in day time.

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

4.2.4 Types of stomata

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

1. **A 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 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 long axis of guard cells and the stomatal pore. This type of stoma is present in the members of Rubiaceae, Leguminosae, Magnoliaceae. e.g. and in *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 stomata can be seen in the members of Caryophyllaceae, Acanthaceae, etc. e.g., *Dianthus* sp., *Hygrophila* species.
5. **Hemiparacytic** : There is a single subsidiary cell parallelly 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 and out of them two subsidiary cells remain on the polar sides and the other two on the lateral sides of the guard cells as found in *Rhoeo* sp.

9. **Hexacytic** : Here six subsidiary cells present surround the guard cells. Two of them are situated on the two polar sides and rest four subsidiary cells are found to 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, pandenaceae and cyclanthaceae.

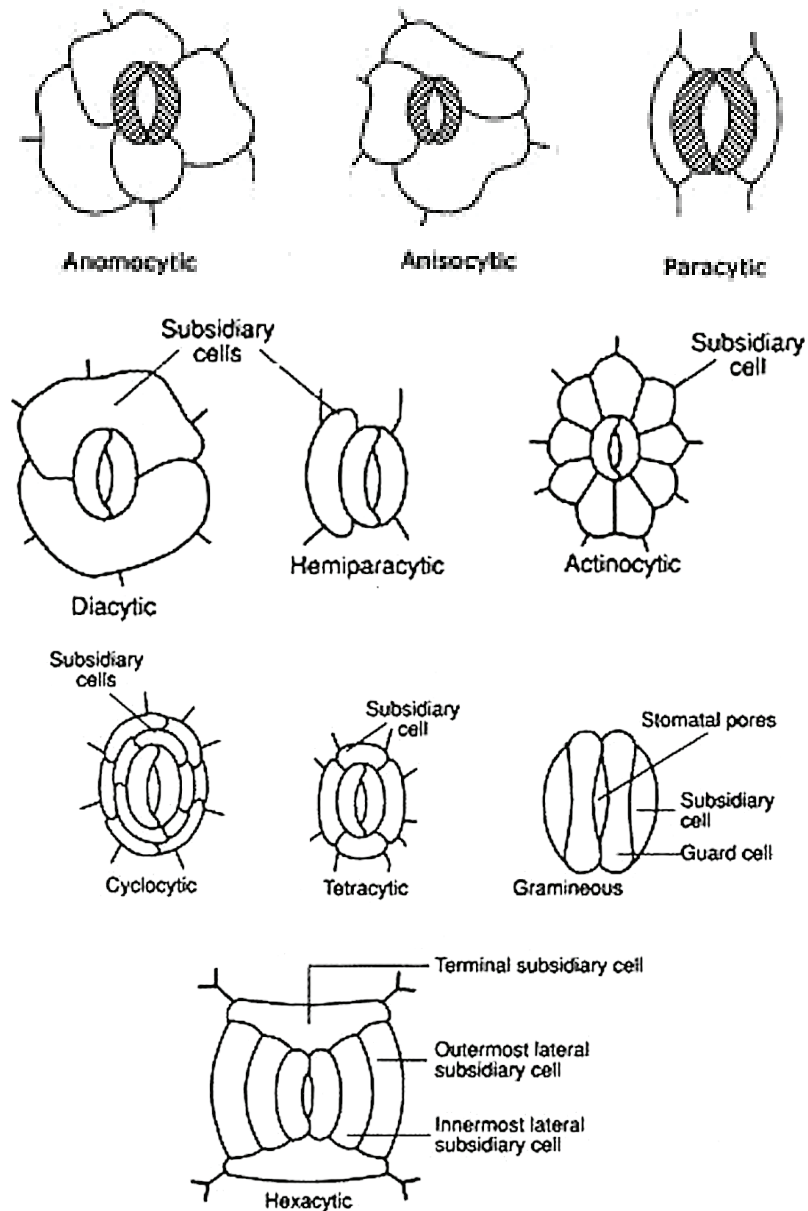


Fig. 27a : Drawings representing different types of stomata.

10. **Gramineaceous** : 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*.

4.2.5 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 rest two at the polar sides of guard cells.

2. **Second type** : Here also there are 4-6 subsidiary cells and out of them two are rounded and smaller in size and each lies 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 guard cells.
3. **Third type** : Here, two guard cells of a stoma are surrounded by two subsidiary cells each remaining on the lateral sides of a guard cells, e.g. *Juncus effusus*. This is the most predominant type of stomatal complex found in 24 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 very common type found in the families like—Amaryllidaceae, Iridaceae, Orchidaceae, Agavaceae, etc.

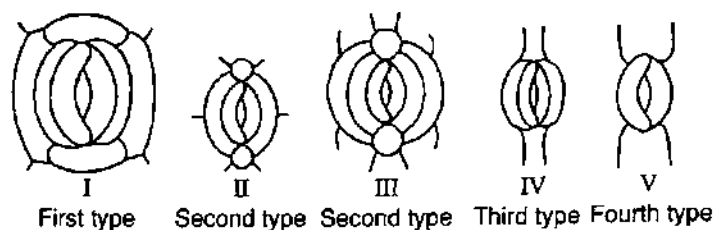


Fig. 27b: Diagrammatic drawing representing types of stomata according to Stebbins and Khush (1961)

4.2.6 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 common origin.

Functions of stomata :

On the physiological point of view stomata are very important and functions of stomata are as follows :

- (i) To take part in gaseous exchange between plant organs and atmosphere during respiration and photosynthesis.
- (ii) To eliminate excess of water absorbed by root system by the process of transpiration.
- (iii) To carry out photosynthesis in the guard cells due to presence of chloroplasts.

4.3 General account of adaptation in xerophytes and hydrophytes

4.3.1 Introduction

Xerophytes are the plants of relatively dry habitats in soil. The xerophytic plants are desert living and they adopt themselves to grow on places where there are (i) scarcity of water, (ii) abundance of soluble salts in the soil, (iii) richness of humus 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 also water requirement of the plant to a minimum.

These adaptations are found in all the characters of the plants as of morphological, anatomical as well as physiological adaptation. Plants growing on rocks, and sand hills, 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 average plants. Due to their aquatic habit they modify their morphological and anatomical structures and even their physiological characters.

4.3.2 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 that of stem or the aerial parts.
- (ii) Roots are elongated and primary roots are tap root type. Roots are highly branched and grow in wide spread 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 few cases stem is rhizomatous as in *Saccharum officinarum*.
- (iii) Sometimes stems are fleshy, juicy, green like that of leaves, known as phylloclade. e.g. *Opuntia dillenii*
- (iv) Stems are with hairs or with waxy covering.

Leaves

- (i) Leaves are small and transform into scale leaves and persist for a short period.

- (ii) In 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 persists then these are thick, fleshy and become leathery.
- (vi) Leaves are smooth and glossy to reflect sunlight.
- (vii) Leaf margins of few monocotyledonous plants like *Ammophila* sp., *Agropyron* sp. are folded in such a manner that sunken stomata remain hidden. Thus to reduce the rate of transpiration.
- (viii) In case of *Acacia nilotica*, *Ziziphus mauritiana* the stipules are transformed into spines.

Anatomical adaptation

Roots :

- (i) Root hairs and root cap are well develop and in case of *Opuntia dillenii* root hairs are present upto root tip.
- (ii) In *Asparagus racemosus* roots are swollen and having water storage tissue.
- (iii) Cell wall of root is rigid and thick.

Stem :

- (i) Water storage tissues present in the fleshy xerophytic stem, e.g. *Aloe barbadensis*
- (ii) Fleshy xerophytic stem is with thick cuticle.
- (iii) Epidermis is well developed and cell wall is with thick cuticle.
- (iv) 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 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.

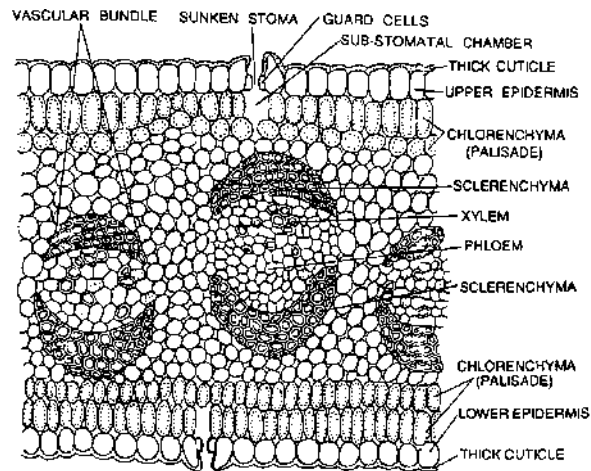


Fig. 28: Anatomy of xerophytic leaf. V.S. of leaf of *Agave* (monocot) showing detailed structure.

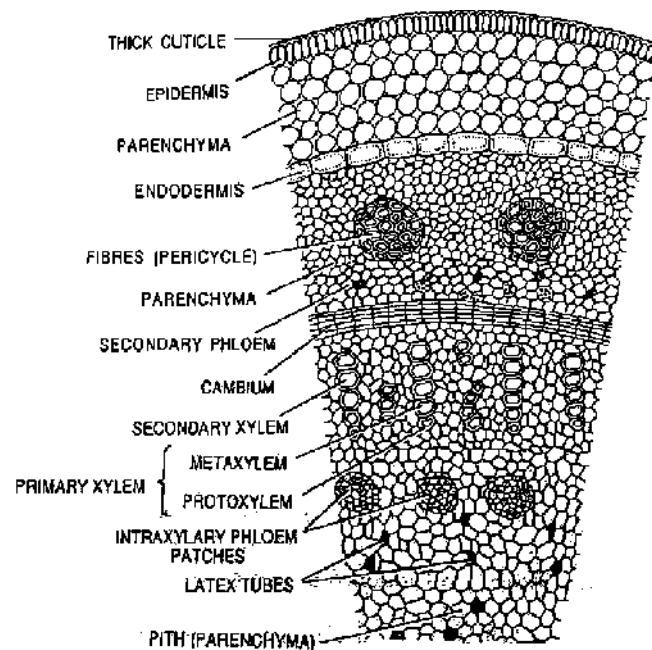


Fig. 29: Anatomy of xerophytic stem. T.S. of a sector of *Calotropis* stem (dicot.)—detailed structure.

Leaves

- (i) Epidermal cells of fleshy leaves act as water storage tissue, e.g. *Peperomia pellucida*.
- (ii) Water remain 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 in *Nerium oleander*; and *Pinus* sp.
- (v) Epidermis is multilayered and hypodermis is made up of sclerenchymatous 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 and are surrounded by hairs in the leaves of *Nerium* sp.
- (viii) Mechanical tissue is well developed. Transfusion tissue present in the leaves of *Pinus* sp. along with sunken stomata (Fig. 30).

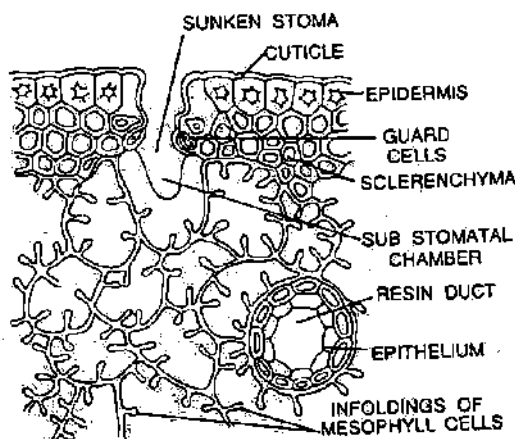


Fig. 30: Structure of xerophytic leaf (microphyllous type). C.S. of a marginal part of leaf of *Pinus nigra*.

Physiological adaptation

- (i) Rate of transpiration is very low.
- (ii) Certain plants like *Solanum virginianu* (*S. surratensise* completes its life cycle in a very short span of time, this is known as 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.

4.3.3 Adaptive features in hydrophytic plants

Morphological adaptation

Root :

- (i) Mostly the roots are absent, e.g. *Wolffia orrhiza*, *Ceratophyllum demersum*.
Roots if present then these are scanty as in *Hydrilla verticillata*.
- (ii) Large amount of roots are present in the plants growing in mud. e.g. *Ranunculus sceleratus*.
- (iii) Roots are devoid of root hairs, if present it is very scanty.
- (iv) Usually roots are without root cap.
- (v) In few plants like (*Ludwigia adscendens* *Jussiaea repens*) floating roots are present in addition to normal roots.

Stem

- (i) Stem of immersed plant like *Hydrilla verticillata* is thin, elongated, spongy.
- (ii) Stem of free floating hydrophytes like *Azolla pinnata* is long, thin floats on water or stoloniferous in *Eichhornia crassipes*.
- (iii) Stems of few plants are rhizomatous as in *Nymphaea pubescens*, *Nelumbo nucifera*.
- (iv) Runner, stolon, offset, 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 dissected type e.g. *Ceratophyllum demersum*.
- (ii) Floating leaves like *Nelumbo* sp., *Nymphaea* sp. are large sized, flat, smooth and upper surface is covered with waxy coating.
- (iii) Floating leaves are with long petiole. Petiole 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 thin cuticle.
- (ii) Epidermis is unilayered and is constituted with thin-walled parenchyma.
- (iii) Cortex is well developed, constitutes with thin-walled parenchymatous cells. Large portion of cortex is with 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 vessel.
- (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) Well developed epidermis is present in rhizomatous stem in case of *Nymphaea* sp. and *Nelumbo* sp.
- (iv) Stems of immersed plants do not have hypodermis. But in the 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) Large number of air cavities are present in the cortex. Cortical cells are with chloroplast, so they help in photosynthesis (Fig. 31).
- (vii) Vascular bundles are without bundle sheath. Conducting tissues are with thin-walled cells.
- (viii) Mechanical tissues are absent.

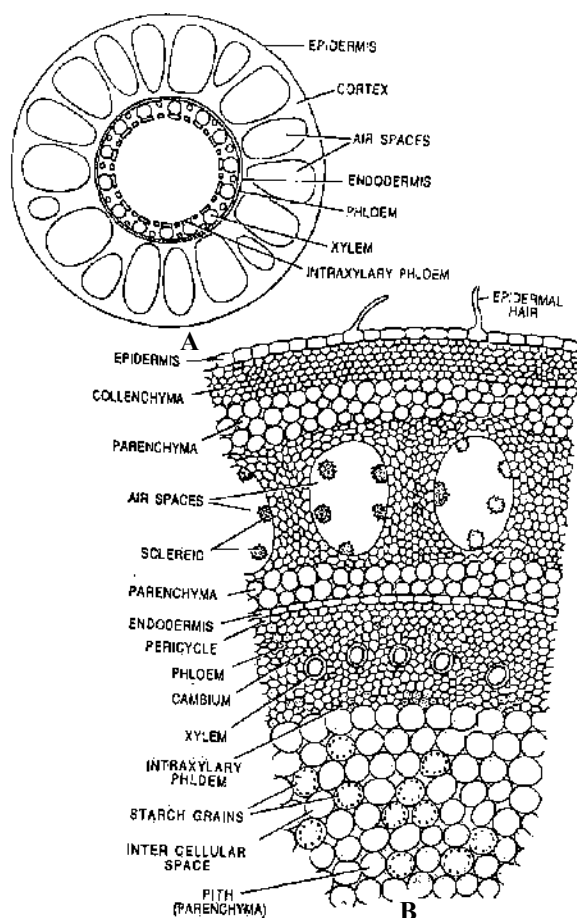


Fig. 31: Anatomy of hydrophytic stem: *Trapa bispinosa* (dicot.) A, diagrammatic; B, detail—T.S. showing epidermis, cortex, vascular cylinder and large pith. Cortex consists of collenchyma and parenchyma; big air spaces in the cortical region. Calcium oxalate sclereids present in the cortex. The endodermis, 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 it is constituted of thin-walled parenchymatous cells and with large amount of chloroplast.
- (iv) Stomata are absent in immersed hydrophytic leaves. e.g., *Anacharis* sp. *Potamogeton* sp.
- (v) Stomata are restricted only at the upper surface of floating leaves. Stomata are present on both the 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 few cases like *Anacharis* sp., xylem and phloem tissues are not well distinguishable.
- (ix) Xylem and phloem is clearly visible in the leaves of floating leaves.
- (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 paucity of oxygen in their habitats.
- (ii) Low demand of oxygen can be seen in certain hydrophytic plants.
- (iii) Gaseous exchange is performed due to presence of air cavitation.

4.4 Summary

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

4.5 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 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.

4.6 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 5 □ Structural Organization of Flower

Structure

5.0 Objective

5.1 Introduction

5.2 Structure of anthers and pollens

5.2.1 The number of stamens varies from one to many

5.2.2 Attachment of anther to the filament

5.2.3 Forms of anther lobes

5.2.4 Dehiscence of anthers

5.3 Structure of Pollen grains

5.4 Structure of ovule

5.5 Types of ovules

5.6 Types of Embryo sacs

5.7 Organization and ultrastructure of mature embryosac

5.8 Summary

5.9 Questions

5.10 Answers

5.0 Objective

This unit helps to gather knowledge related to the structural organization of flower, specially anther and pollen structure, forms of anther lobes, attachment of anther to the filament. Anther dehiscence mechanism. Ovule structure, types of ovules, development of different types of embryosac, etc.

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.

5.2 Structure of anthers and pollens

The androecium is the first essential and third member of the floral whorl. 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 filamental its tip. Each anther consists usually of two lobes connected together by a sort of midrib known as the connective. Each anther lobe contains two pollen-sacs

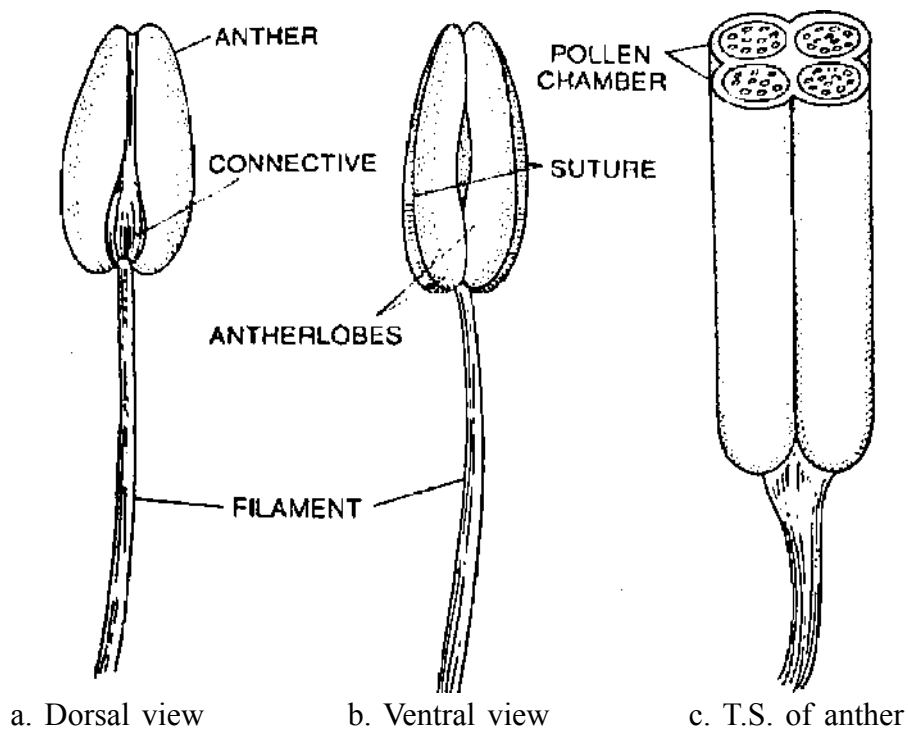


Fig. 32 : a. Stamen, a–dorsal view; b–ventral view; c–T.S. of anther

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 homogenous mass of meristematic cells surrounded by an epidermal layer. Further growth of the anther makes it four lobed (Fig. 32c).

5.2.1 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.

5.2.2 Attachment of anther to the filament

The anther becomes attached with 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 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 quadricellular, 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*.

Sagittate : Anthers are arrowshaped e.g. *Catharanthus roseus*.

Sinuous : Here, anther lobes convoluted forming 's' shaped structure e.g. *Cucurbita maxima*.

Filamentous : Lobes of anther is thread like e.g. *Zostera* sp.

5.2.4 Dehiscence of anthers

The pollen grains inside the mature anther exert some pressure on the outer wall, there by 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 : Pollens are discharged through apical pores e.g. *Solanum tuberosum*, *cassia* sp.

Valvular : Pollens are discharged through a trap-door-like valve formed on the anther wall, eg. *Berberis vulgaris*, members of Lauraceae as *Cinnamomum*, *Litsea* etc.

Longitudinal : The anther lobes burst length wise along the line of suture from base to apex, e.g. *Datura* sp., *Vitis vinifera*.

5.2.5 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 body which separates the two anther lobes, of which one is sterile and the other one is fertile, e.g. *Salvia plebeja*.

5.3 Structure of Pollen grains

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

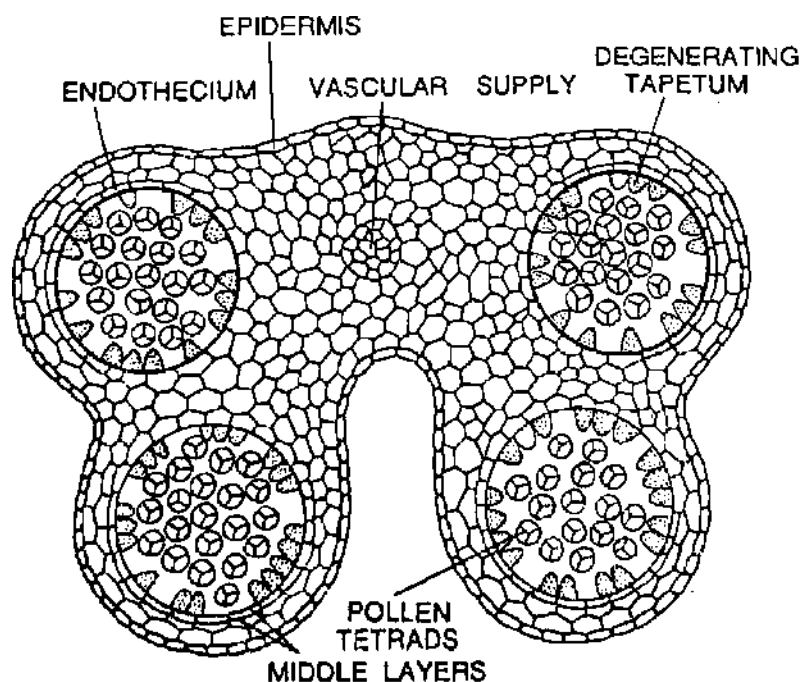


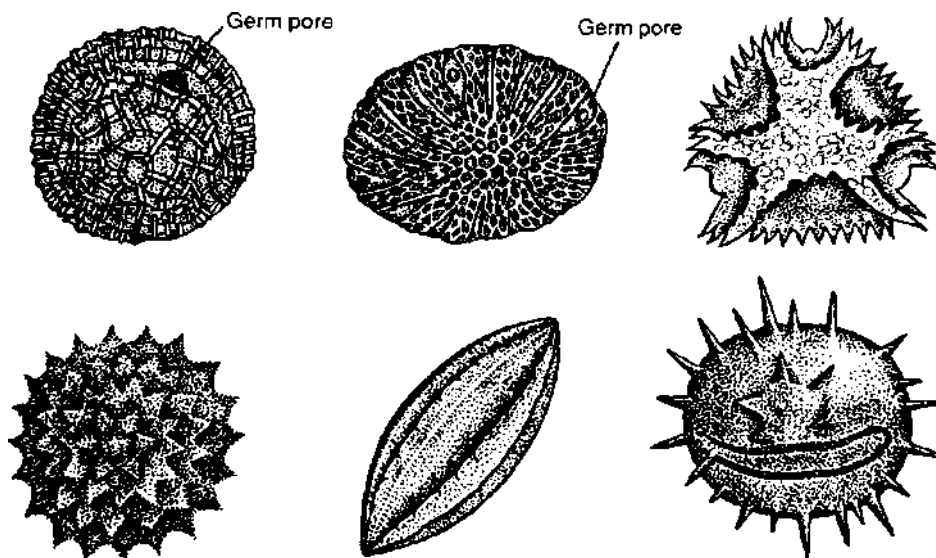
Fig. 33 : Anther. T.S. of an anther showing tetrads of pollen grains.

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 gymnosperm and angiosperm group of plants. Pollen grains which develops with the microsporophyll of Gymnospermic group of plant and within the anther of 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 orektexine 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 extenal 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 angustata* 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. 34 :

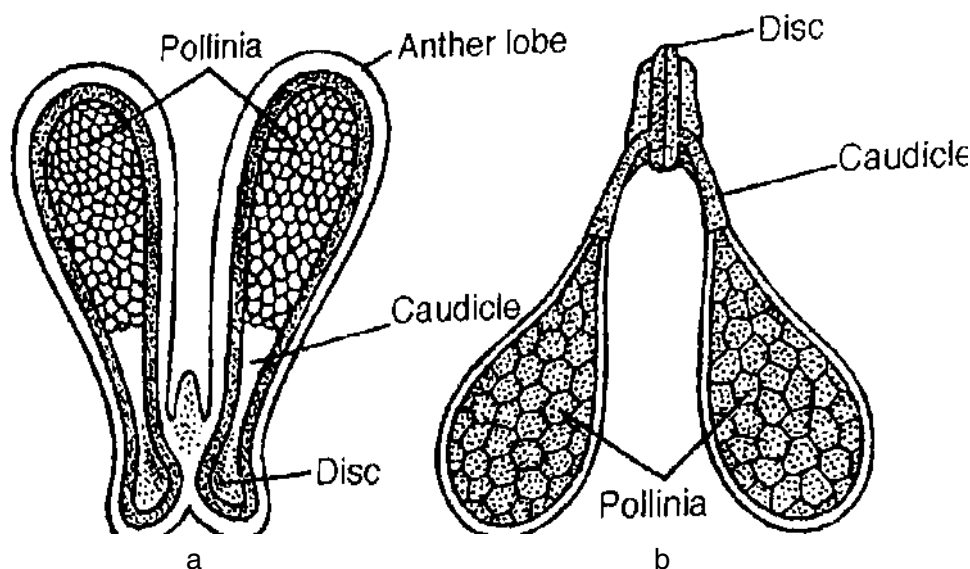


Fig. 35 : Pollen grains and Pollinia : a. Pollinia of *Orchis* sp. b. Pollinia of *Calotropis procera*

5.4 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

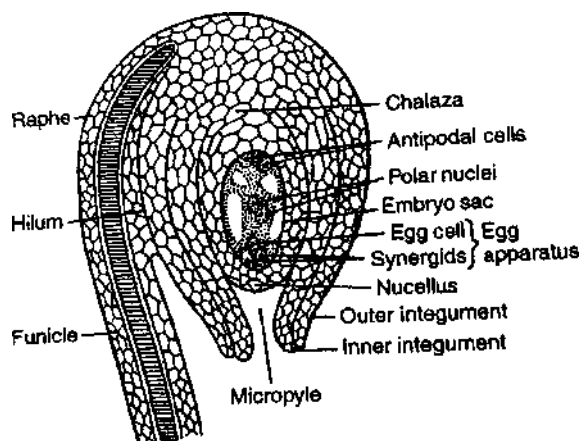


Fig. 36 : Longitudinal section of a typical ovule of angiosperm (anatropous type)

the ovule, forming a short of 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 this is called the micropyle. When there are two integuments then the inner integument is formed first and 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 bears the embryo later on.

5.5 Types of ovules

On the basis of the relative position of the micropyle, chalaza and funiculus of the mature ovules as found in angiosperms that are of 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 funicle, 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 funicle 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. *Moraceae*, *Pisum sativum*.
- (c) **Amphitropous or Transverse** : The ovule is placed transversely at a right angle to the stalk or funicle, 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 right angle and so the chalazal micropyle line is at right angle to the funiculus. It is found in *Ranunculus*.
- (e) **Campylotropous or curved** : In this type the transverse ovule is bent round like a horse shoe 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.

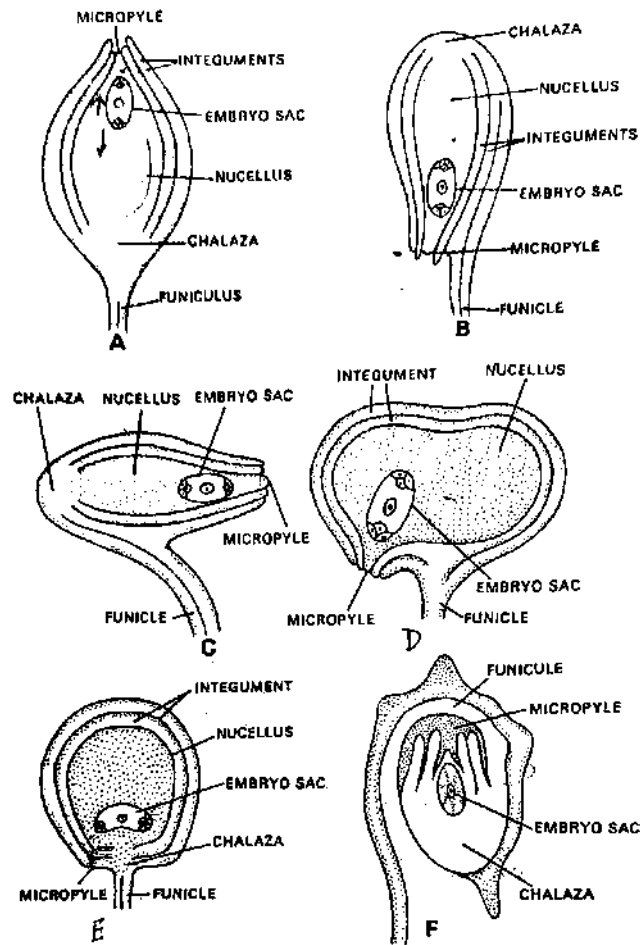


Fig. 37 : Different types of the ovule in longitudinal section. A. orthotropous; B. anatropous; C. amphitropous; D. hemianatropous; E. campylotropous F. circinotropous.

5.6 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 the embryo sacs of angiosperms may be classified into three main categories as monosporic, bisporic and tetrasporic.

In monosporic type only one of the four megaspores takes part in the development of the female gametophyte or embryo sac. In bisporic type two megaspore nuclei take part in the development of female gametophyte or embryo sac. However, in tetrasporic type all the four megaspore nuclei take part in the development of female gametophyte or embryo sac.

They have been further subdivided into following types (Fig. 38) on the basis of the number of the nuclear division takes places 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 is said to be monosporic. The female gametophytes or embryo sacs of this type may be 8 nucleate and 4 nucleate.

1. *Polygonum* or Normal type

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

In the development of 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 in 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.*, embryo sac increases in size. Now one nucleus from each pole passes inwards and the two polar nuclei fuses 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

TYPE	MEGASPOROGENESIS			MEGAGAMETOGENESIS			
	Megaspore mother cell	Division I	Division II	Division III	Division IV	Division V	Mature embryo sac
Monosporic 8-nucleate <i>Polygonum</i> type							
Monosporic 4-nucleate <i>Oenothera</i> type							
Bisporic 8-nucleate <i>Allium</i> type							
Tetrasporic 16-nucleate <i>Peperomia</i> type							
Tetrasporic 16-nucleate <i>Penaea</i> type							
Tetrasporic 16-nucleate <i>Drusa</i> type							
Tetrasporic 8-nucleate <i>Fritillaria</i> type							
Tetrasporic 4-nucleate <i>Plumbagella</i> type							
Tetrasporic 8-nucleate <i>Plumbago</i> type							
Tetrasporic 8-nucleate <i>Adoxa</i> type							

Fig. 38 : Development of different types of embryo sac in angiosperms (after Maheshwari)
[Micropyle above in all illustrations]

apparatus. 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 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 embryo sac so 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 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 the four megaspore nuclei take part in the development of embryo sac is known as the tetrasporic type. In several cases 16 nuclei are formed with the 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 towards the periphery of the embryo sac. Two nuclei at the micropylar end form an egg and synergid; 8 are fused to form the secondary nucleus and the remaining 6 nuclei are cut off at the periphery of the embryo sac. This 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 towards 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 member 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 antipodals. The four micropylar nuclei give rise to the egg apparatus and the upper polar nucleus, and the twelve chalazal nuclei to 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 1 + 2 + 1 arrangement i.e., one nucleus lies at each pole and two in the centre. The two nuclei of the centre remain quite close to each other but do not fuse together. Now the megaspore nucleus of micropylar end divides twice forming four nuclei but there is no regularity in the division of the nucleus of chalazal end. Thus embryo sac may have six, nine and 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 micropylar end; one haploid pair at 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 upper haploid polar nucleus. The four haploid antipodal cells are formed at chalazal end. One of the diploid nuclei of the central quarter behaves as the lower polar nucleus and the remaining three organize them 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 towards the micropyle, and the rest three at the chalazal end. The chalazal nuclei fused together and form

$2n$ 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 at the chalazal end and one from each pole remain 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 *Fritillaria* type which forms 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 nuclei at the centre. It is found in *Plumbagella* of Plumbaginaceae.

11. *Plumbago* type

This type of development of embryo sac has been reported in *Plumbago auriculata capensis* P. (Haupt by 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 approach each other in the centre and fuse to form a tetraploid secondary nucleus. The remaining three nuclei degenerate.

12. *Adoxa* type

This type of development of embryo sac 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 regular feature in *Adoxa* and *Sambucus*.

5.7 Organization and ultrastructure of mature embryo sac

In majority of angiosperms, the eventual organization of embryo sac shows a uniform pattern, whereas the origin of mature embryo sac may differ. The *Polygonum*,

Allium, *Fritillaria* and *Adoxa* types have similar appearance at the time of fertilization (i.e., three-celled egg apparatus, three antipodal cells, and two polar nuclei). However in 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 which degenerate and disappear soon after fertilization or sometimes before it. As a rule, each of the synergids 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 lie in the lower part of the cell and the vacuole in the upper (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 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, and eventually gives rise to the endosperm, and therefore, known as endosperm mother cell. Usually the two nuclei coming from two different poles are similar in appearance, but sometimes the micropylar polar nucleus is bigger one (Fig. 39c). The fusion of the polar nuclei may occur either before, or during, or sometimes after the entry of the pollen tube inside the embryo sac.

Ultrastructural organization of cells in the mature embryo sac of natural tetraploid *Trifolium pratense* was investigated. 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 nucleated 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 antipodals at the chalazal end.

The large bases of synergid cells cover the egg cell partially and the polar nuclei remain very close to the egg apparatus (Fig. 39a). Longitudinal section of the mature embryo sac shows the presence of large and ovate egg cell. Its width is broader at the chalazal end and gets narrower towards 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 they are more concentrated in the micropylar region of the cytoplasm. 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 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. Large vacuole and several small vacuoles located throughout the cytoplasm at the chalazal end of the cell, (Fig. 39b).

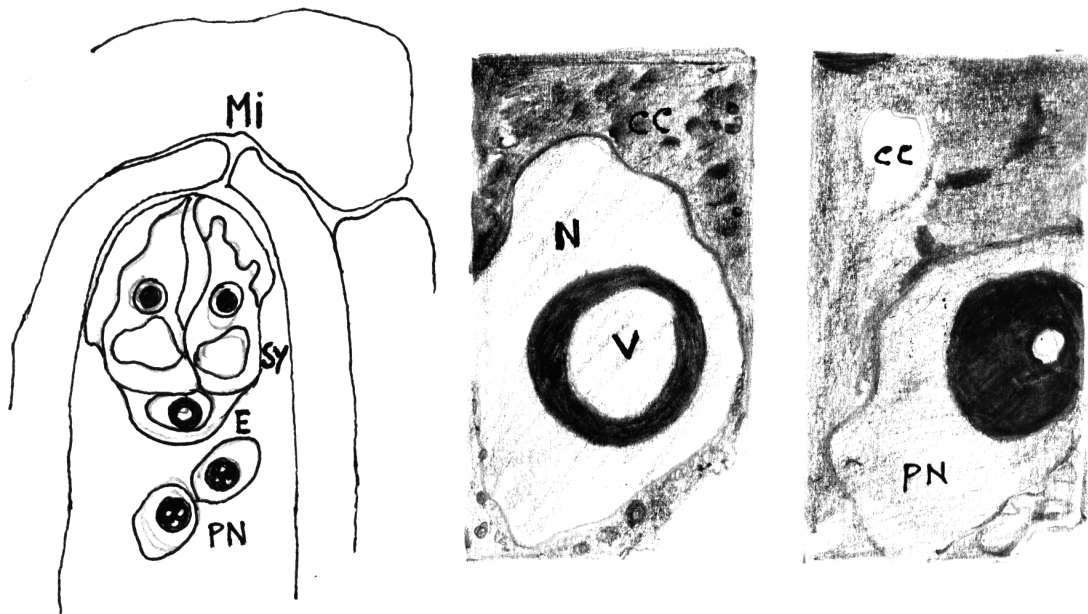


Fig. 39a : Longitudinal section of the micropylar end of the mature embryo sac showing the egg cell (E), two synergids (SY) and two polar nuclei (PN).
b : Electron micrograph showing the nucleus (N) and the nucleolus (NU) containing a big central vacuole (V).
c : Electron micrographs showing a longitudinal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

5.8 Summary

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

5.9 Questions

1. With suitable illustration describe the structure of a 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.
5. Define embryo sac. Give detailed outline of a tetrasporic embryo sac and mention their types.

5.10 Answers

1. See article no. 5.2
2. See article no. 5.2.1 & 5.2.2
3. See article no. 5.2.3 & 5.2.4
4. See article no. 5.4 & 5.5
5. See article no. 5.6

Unit 6 □ Pollination and Fertilization

Structure

- 6.0 Objective**
- 6.1 Introduction**
- 6.2 Pollination mechanisms and adaptations**
- 6.3 Pollination mechanism**
- 6.4 Adaptations for self pollination**
- 6.5 Adaptations for cross pollination**
- 6.6 Double fertilization**
- 6.7 Seed structure; appendages and dispersal mechanism**
- 6.8 General structure of seed**
- 6.9 Dispersal**
 - 6.9.1 Dispersal by wind**
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 - 6.9.3 Dispersal by animals**
 - 6.9.4 Dispersal by explosive mechanism**
- 6.10 Summary**
- 6.11 Questions**
- 6.12 Answers**

6.0 Objective

From the study pollination mechanisms, adaptations, double fertilization process, seed structure, various modes of seed dispersal mechanism, etc. can easily be understood.

6.1 Introduction

Pollination is the transference of pollen grains from the anther to the stigma whether of the same flower or of a different flower.

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.

6.2 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 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 male or bisexual flower to the stigma of female or another bisexual flower occurring in the same plant 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 when takes place between two different plants of the same species is termed as xenogamy and between two different species is known as hybridism.

6.3 Pollination mechanism

Mechanisms of pollination are different. However in case of 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 long connective, the anterior end of the connective forms a knob at the end of 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 in the lower side of the hypogynous disc. The single anther lobe of stamens is concealed in the head

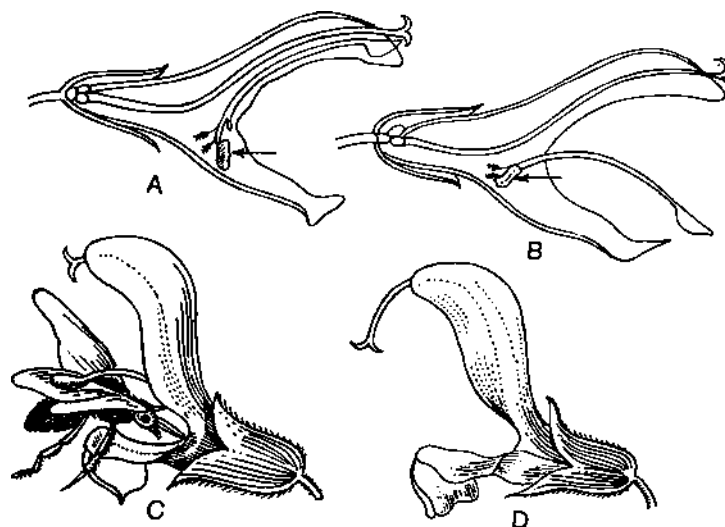


Fig. 40 : Pollination mechanism in *Salvia* sp. (steps of pollination shown).

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 sterile anther, as a result of which upper fertile anther lobe strikes on the back of the bee. The back of the bee is thus dusted with pollens. The style with forked stigmas forms a bent structure. As the bee with the pollen powder on its back enters another mature flowers, the pollen powders are caught by the forked recurved stigmas from the back of the bee. The flowers of *Salvia* are highly protandrous and have corolla arrangement of 2/3 type i.e. upper lip of two lobes and lower of three lobes.

- (ii) In *Lathyrus odoratus* (Papilionaceae) the construction of the flower itself is an adaptation for cross pollination by insects, commonly by bee. The standard is the flag apparatus, the wing petals i.e., carina are the landing stage of insects. The flower is so constructed that the weight of the insect on 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 insects.
- (iii) In *Calotropis* sp. (Asclepiadaceae) there is highly elaborated arrangement for cross pollination by means of insects e.g. bees. The corona like appendages are associated with the secretion and storing nectar in *Calotropis*. Here the pollen is not granular but aggregated into two waxy masses—the so called pollinia which are attached with each other by slender stalk like processes known as

translators which end in a notched knob-like structure, the corpusculum. Stamens and pistils are adherent to form gynostegium. The anthers are adherent on the lateral sides of the pentagonal stigma (Fig. 41). There are small openings or slits between the adjacent cells of anther. A bee or other insects in search for nectar

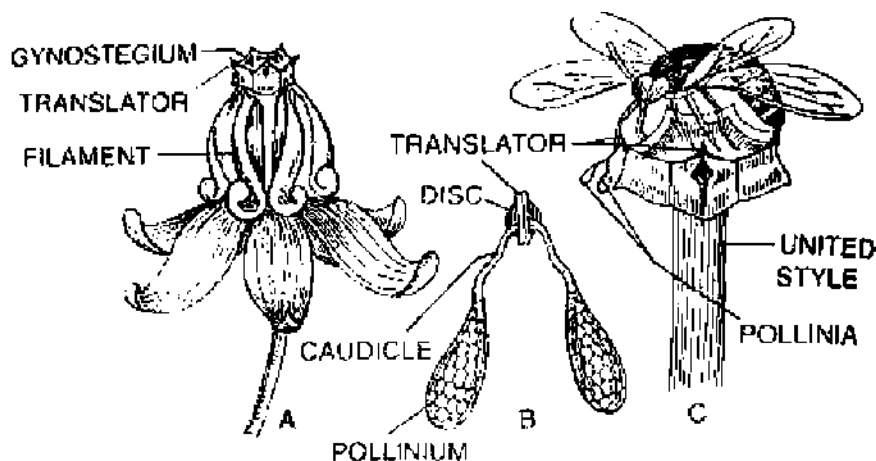


Fig. 41 : Pollination mechanism in *Calotropis* sp. A—Flower. B—A pair of pollinia. C—A bee removing a pair of pollinia from the gynostegium.

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 insect. The insect when retiring from the flower 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. So, cross-pollination is easily brought about by insect.

- (iv) In *Ficus* sp. (Moraceae), the flowers are adapted for cross-pollination by 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 i.e. gall wasps

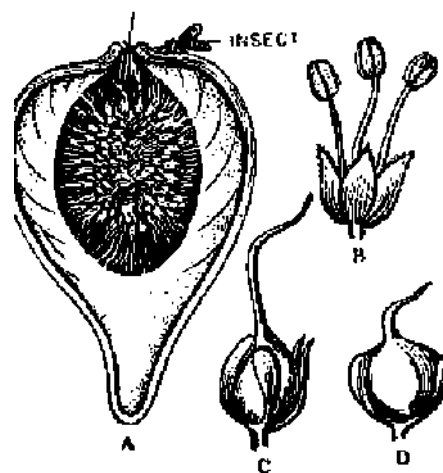


Fig. 42 : Pollination mechanism in *Ficus* sp. (fig) —L.S. of the hypanthodium showing the entry of gall wasp. B—Male flowers. C—Female flowers. D—Gall flowers.

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 there, the bodies of wasps are dusted with pollens. 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. gynoecium matures earlier than anthers.

Small insects are attracted by the foul odour and bright colour of the flowers. The deflected hairs allow the entry of the 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 of other flower. Later on, the hairs wither, enabling the fly to escape.

- (vi) In *Vallisneria spiralis* (Hydrocharitaceae), the flowers are borne under water. 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 water. If the male flowers gets lodged into the depression, pollination occurs.

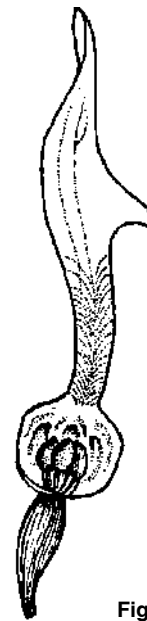


Fig. 43 :

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).

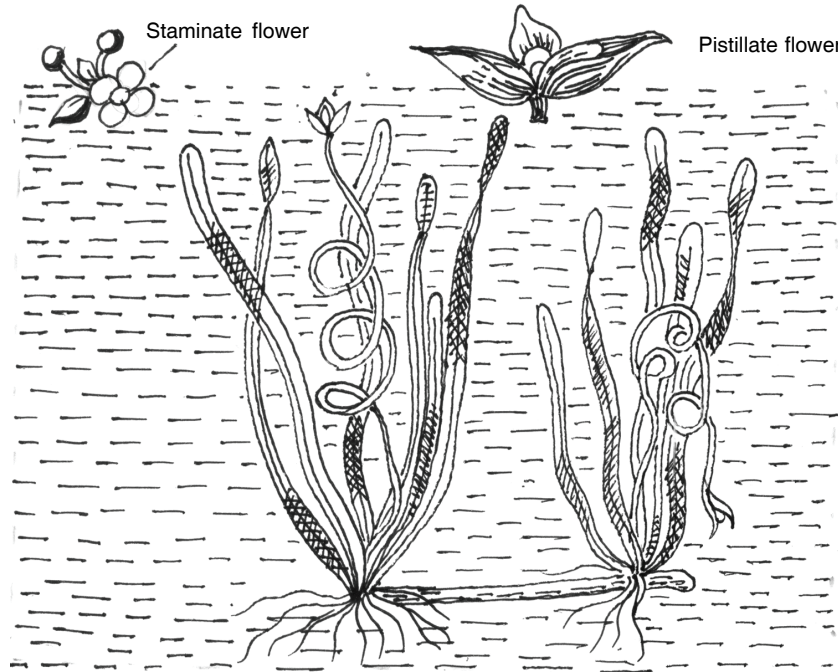


Fig. 44 : Pollinationo (epihydrogamy) in vallisneria spiralis

(vii) In orchid flower highest level of adaptation for cross pollination by insects is developed (Fig. 45). The labellum i.e. the posterior median member of the inner

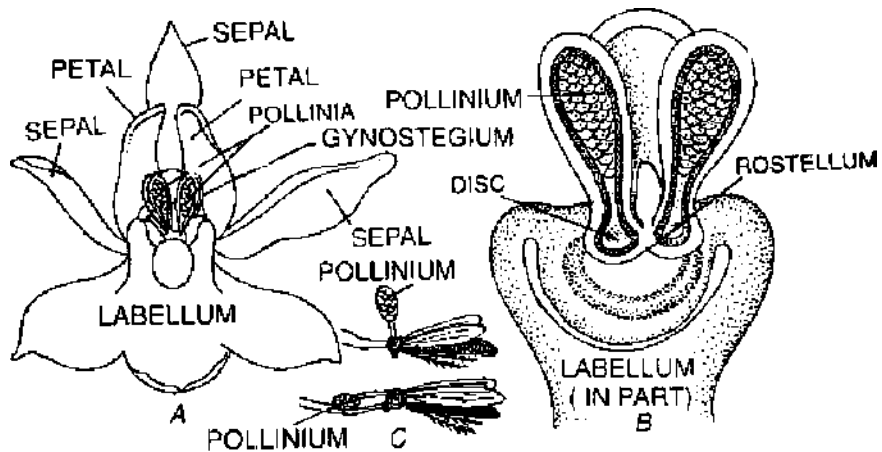


Fig. 45 : Pollination mechanism in an orchid flower. A—Flower showing different parts. B—Gynostegium only (enlarged). C—One bee carrying pollinia.

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 acts as the flag and landing stage for the flies. The rostellum i.e. the sterile extension from the upper edge of the 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 labellum to get nectar concealed in the spur. During its attempt the insect pushes back the rostellum and even breaks it. So the pollinia are released and get stuck to leg or forehead of insects by the disc with the help of sticky fluid. At first the pollinia stand erect but due to flexible nature of caudicle they bend down during the movement of fly. During visit of insect to other flower the pollinia get caught by the sticky fluid of the stigma and gradually the pollens are released. So, the cross pollination is effected.

6.4 Adaptations for self pollination

- (i) **Cleistogamy** : It is the state of condition of being self-fertilized of flowers usually without opening. Various types of adaptation in cleistogamous flowers belonging to different families are met with. In *Viola* sp. there are apetalous flower or flowers 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 pollens from the anther of other flower to the stigma of closed flower. But brightly coloured 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 they become closed permanently e.g., *Drosera burmanii*, *Oxalis corniculata*, *Portulaca oleracea*, etc.

- (ii) **Homogamy** : It is the condition of the maturity of anthers and stigmas of the flower at the same time, so that self pollination is effected, although not always. Sometimes pollen grains are carried to the stigma by some agents like wind, insect, 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.

6.5 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 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 the self-pollination becomes hindered. It is again of two types :
 - (i) **Protandry or proterandry** : This is a condition when anthers mature earlier than stigma. So in 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 stigma matures earlier than anthers. Here mature stigma is pollinated by the pollen of other flowers due to 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 sterile condition of the pollen of the bisexual flower and in such cases as a result a flower cannot be fertilised by the pollen of same flower. It is fertilized by the pollens of other flower. eg. *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 pollens are aggregated in pollinia, the pollination is completely depends on the mercy of the insects. In *Iris* sp. the large outer perianth leaf acts as a landing stage for insects, 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 level i.e. flowers may have short styles with long filaments and vice versa in the same flower. Due to this condition of flower self pollination is not effected and so cross pollination takes place between stamens and carpels of same length.

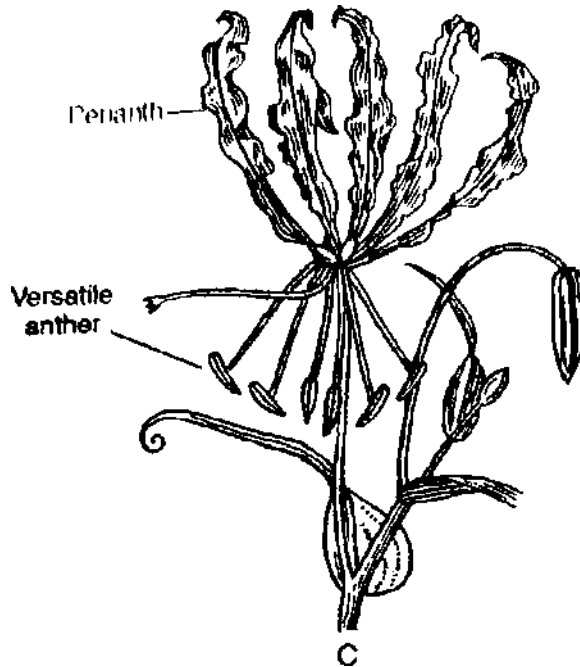


Fig. 46 : *Gloriosa superba* flower-herkogamy.

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

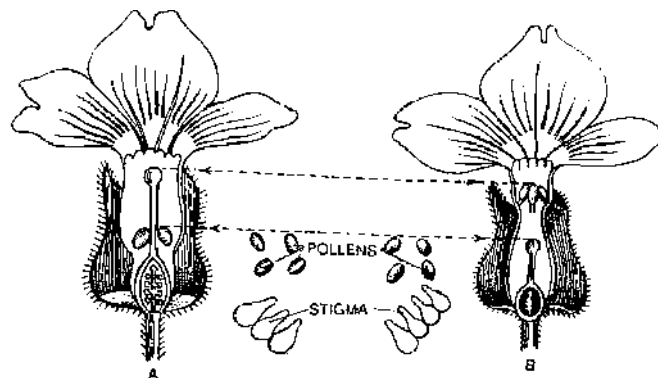


Fig. 47 : Heteromorphism in dimorphic flowers of *Primula* sp. A—Flower having larger gynoecium with higher position of stigma and (st). anthers in lower position with smaller pollens (p). B—Flower having shorter gynoecium with smaller stigma and anthers at higher position with larger pollen grains.

(1.2) The trimorphism is found in *Lythrum salicaria* (Lythraceae), where three different forms of flowers having short, long and medium sized stamens and styles (Fig. 48). It is also found in *Oxalis corniculata* and *Averrhoa carambola*, *Woodfordia fruticosa floribunda* (= w.) etc.

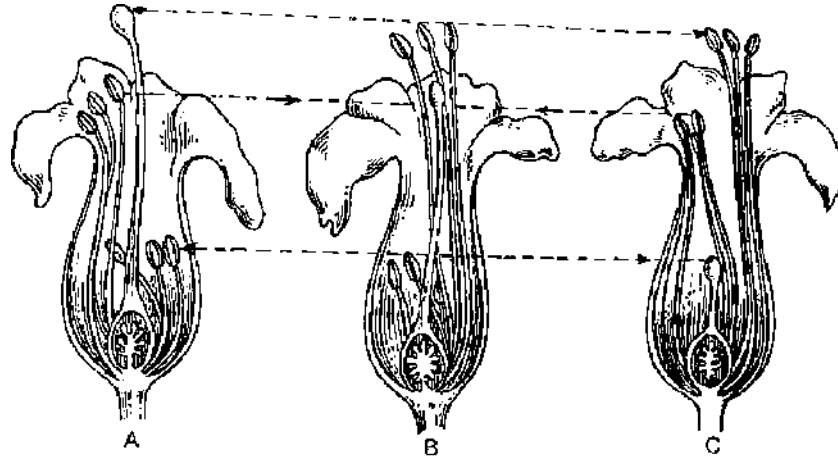


Fig. 48 : Heteromorphism in trimorphic flowers of *Lythrum salicaria* with three different length of stigma and anther position.

6.6 Double fertilization

Fertilization was first discovered by Strasburger in 1884. It is a process where male and female gametes fuse with each other and resulted 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., embryo sac remain deep in the ovarian cavity, quite a long distance from the stigma. The pollen grains after liberating from the anther reaches to the stigma and the viable pollen germinates. During germination the pollen grain develops pollen tube which grows through the style and reaches to 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 pollen tube contains the living cytoplasm with tube nucleus and generative nucleus or a tube nucleus and 2 male nucleus, which are produced from 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 to the top of the ovary the pollen tube may enter through micropyle with its nuclei—called porogamy. Sometimes the pollen tube may enter the ovule in a round about way through chalaza—known as chalazogamy or basigamy or a porogamy as in *Casuarina* sp., *Betula* sp., *Juglans* sp., etc.

In few cases the pollen tube enters the ovule through funiculus or the integuments—this is called as 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 embryo sac the pollen tube may pass between one egg and a synergid or between embryo sac wall and a synergid or directly into a synergid. Usually one synergid is destroyed by the impact of the pollen tube and 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 tip of the pollen tube bursts and both the male gametes set free (Fig. 49).

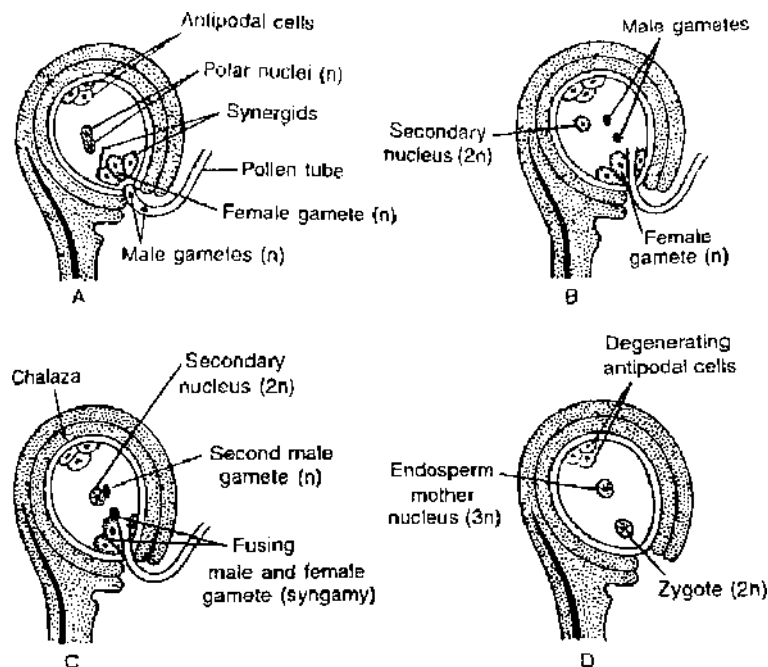


Fig. 49 : A-D. L.S. of ovules showing different stages of fertilisation

One of the male nucleus fuses with the egg nucleus to form oospore or zygote ($2n$) while the other male nucleus fuses with secondary or fusion nucleus—results 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 secondary or fusion nucleus and thus this phenomenon is known as double fertilization. It was first observed by Nawaschin (1898) in *Lilium martagon*.

The fusion of second male gamete (n) with diploid secondary nucleus ($2n$) is the triple fusion and the resultant nucleus is triploid endosperm nucleus ($3n$). Zygote or oospore forms the first cell i.e. the mother cell of the embryo.

6.7 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 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.

6.7.1 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 seed which develops from the integuments of the ovule. It is of two type i.e. testa and tegmen. Testa is hard outer layer and tegmen is thin papery inner layer.

At one end of testa there is a scar known as hilum. Hilum is the position of attachment of seed with its stalk, the funiculus. Near the hilum a small opening is present, known as micropylar through which water enters opening into the seed. Sometimes a ridge is present beyond the hilum, opposite the micropyle, known as raphe.

Tegmen is much thinner than the testa. It is absent in *Pisum sativum*, appressed in *Cicer arietinum*.

- (ii) **Kernel** : The inner part within the seed coat is called kernel. It consists either of the embryo only as in ex-albuminous seeds like *Cicer arietinum* or the embryo enclosed within the endosperm as in albuminous seeds like *Oryza sativa*, *Triticum aestivum*, etc. Sometimes embryo with both endosperm and perisperm are present as in *Elettaria cardamomum*.
- (a) **Embryo** : It remains enclosed in a seed. Embryo consists of cotyledon and tigellum.

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

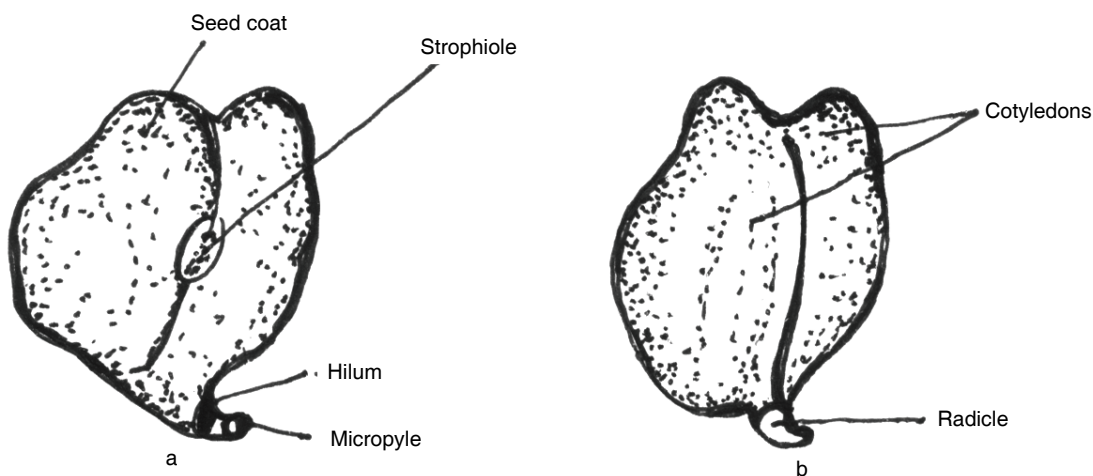


Fig. 50 : Structure of dicotyledonous exalbuminous seeds. a—structure of gram seeds. b—structure of pea seed.

Tigellum (axis) : It is the main axis of which one end is pointed and protrudes out of the cotyledon, it lies next to cotyledonary node and is known as radicle. The other end of the tigellum is the plumule.

In monocotyledonous seeds both radicle and plumule remain covered by protective sheaths, known as coleorhiza and coleoptile respectively (Fig. 51).

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

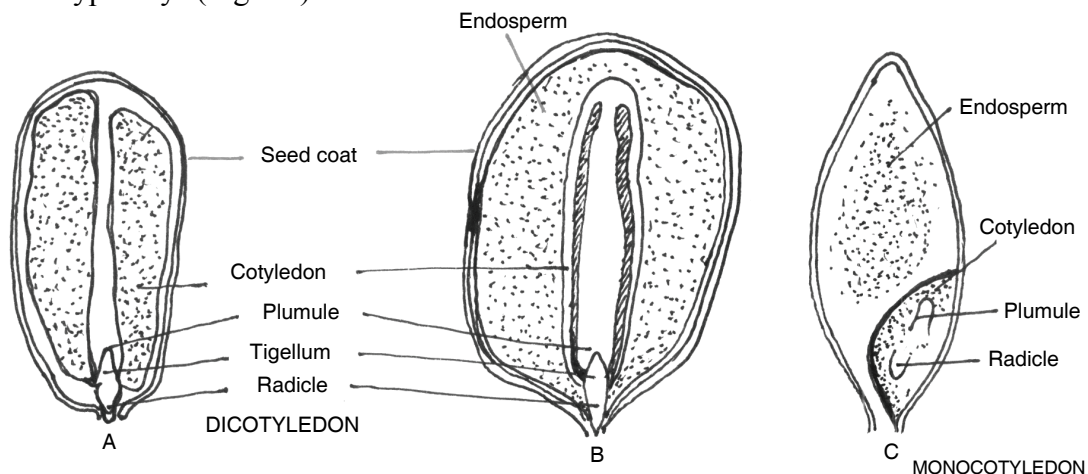
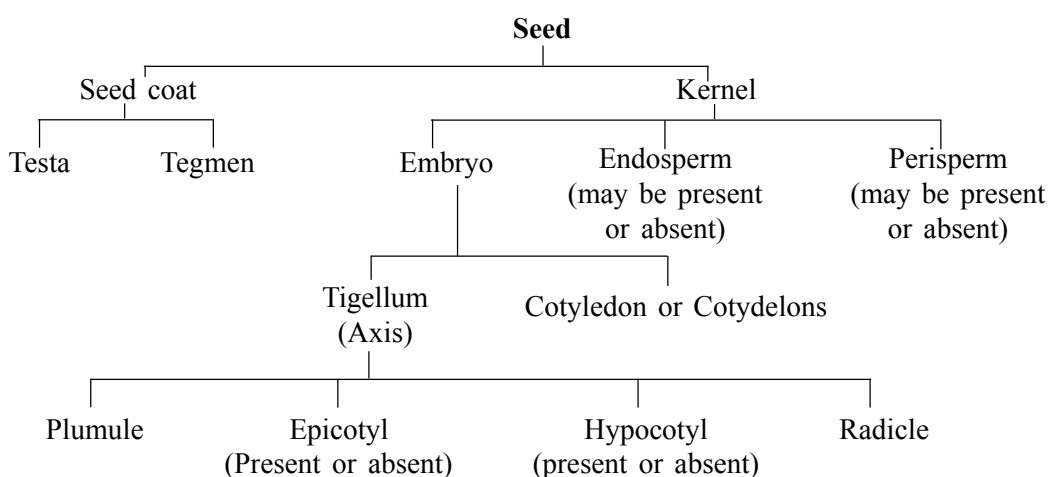


Fig. 51 : General structural differences among the four different types of seeds : A. Dicotyledonous exalbuminous (Non-endosperonic), B. Dicotyledonous albuminous (endospermic), C. Monocotyledonous albuminous (Endospermic).

- (b) **Endosperm :** Endosperm is the food reservoir of seed. It may be starchy e.g. *Triticum aestivum*, oily in *Brassica nigra*, proteinaceous in *Cicer arietinum*.
- (c) **Perisperm :** It is the remnant of nucellus of ovule and is also nutritive in function.

6.8 General structure of seed



6.9 Dispersal

Dispersal is the phenomenon of transfer of plant to a distant place. Seeds are usually formed in abundance so that they may be distributed over a wide area to ensure multiplication of plants. If all the seeds fall near about the mother plant and germinate there, the new plants cannot have healthy growth due to over crowding of population in a small area. The over-crowding of the seedling results 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 morphological construction of seeds varies according to dispersal agencies. So these characteristic morphological features are discussed below in respect to dispersal mechanism by different agencies.

6.9.1 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 distance. 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 out 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 seed coat i.e. testa. e.g. *Moringa olifera* (Fig. 52b) *Oroxylum indicum*, *Swietenia mahagani*.

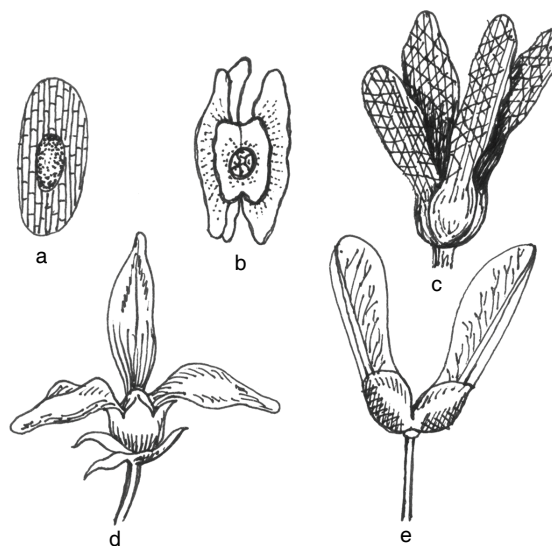


Fig. 52 : Fruits and seeds adapted for wind dispersal : a. Minute and Light seeds of orchid, b–c. Winged fruits and seeds. Wings develop from seed coat of *Moringa*, (b) *Oroxylum*, *Shorea*, (c) Pericarp expands into wings of *Niptage* (d) and *Acer* (e).

- (ii) Wings may develop from persistent sepals e.g. *Dipterocarpus* sp. *Shorea robusta* (Fig. 52c) etc.
- (iii) Wings may develop from 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 parachute by which they remain in the air for long time and can disperse for long distance. The seappendages are :
- (i) **Comma** : Tuft of hairy outgrowth of testa at one end or both ends of seeds help to disperse for long distance. e.g. seeds with one comma as in *Calotropis procera* (Fig. 53a) and comma at both ends of seed e.g. *Alstonia scholaris*.

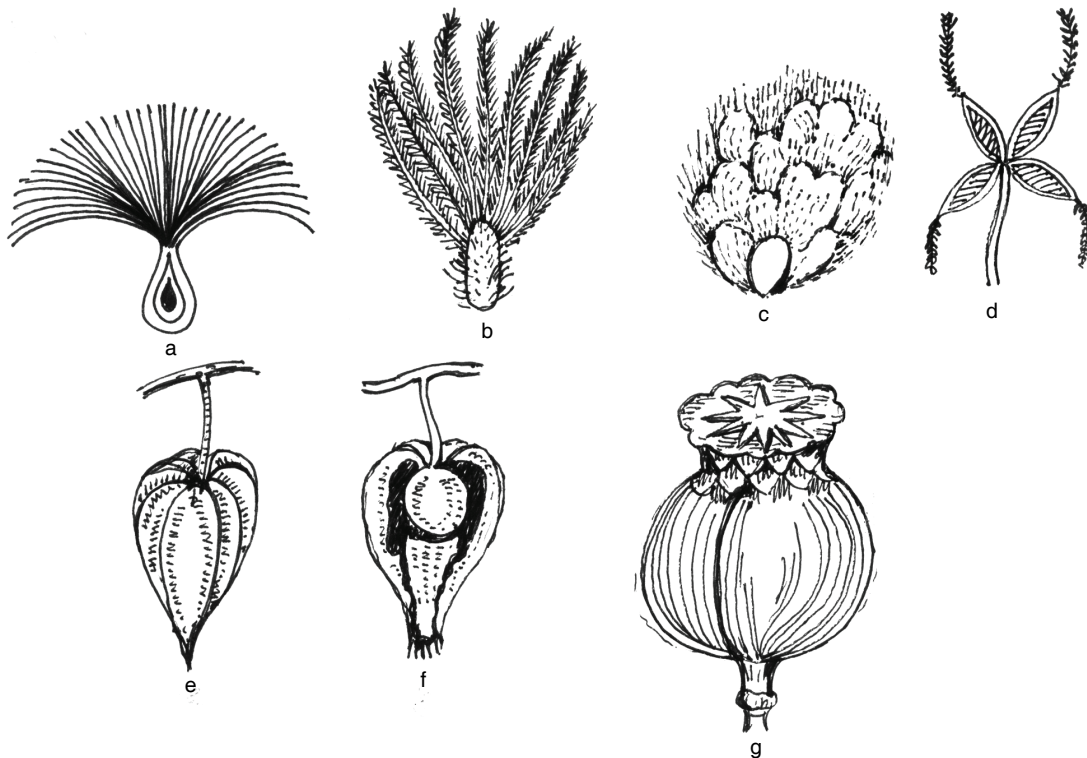


Fig. 53 : Seeds adopted for wind dispersal : a. Coma of *Calotropis*, b. Pappus of *Tridax Procumbens*, c. Hairy outgrowth on seeds of *Bombax Ceiba*, d. Persistent hairy style of *Clematis gouriana*, e. Ballon-Shaped appendages (by inflated calyx of *Physalis*), f. Single enlarged capsule of *P. Somuiferum*.

- (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 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 testa as seen in *Gossypium herbaceum*, *Bombax ceiba*, which helps to disperse a long distance. (Fig. 53c).
- (iv) **Persistent hairy style** : This is seen in fruits of achene by means of which fruits can float in the air and disperse for long distance, e.g. *Clematis gouriana*, *Ceiba pentandra*, (Fig. 53d) *Naravelia zeylanica*, etc.
- (v) **Ballon-shaped appendages** : Ballon-shaped appendages are formed by the modification of different parts of the plant. It helps the fruit and seed to remain in air for longer period.
- It is formed by the inflated accrescent calyx in *Physalis minima* (Fig. 53e), inflated ovaries of legume 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.

6.9.2 Dispersal by water

The aquatic plants and the plants growing on the bank of river or sea-shore disperse their seeds and fruits by water current for a long distance. In such plants the seeds and fruits generally develop floating devices in the form of spongy tissues or fibrous coats, water proof and buoyant nature of coats, etc.

The plants which require water as an agent for dispersal are termed as hydrochorous.

The fruitlets may be embedded in the spongy and water tight thalamus and can be carried away by the water currents as in *Nelumbo nucifera* (Fig. 53g).

In the fruit of *Cocos nucifera*, the fibrous mesocarp is a floating device; the hard endocarp protects the embryo from external injury—so, the fibrous coconut fruit is capable of floating long distance in water without suffering any from

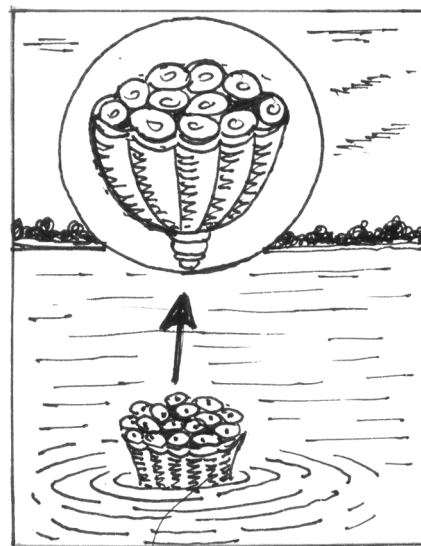


Fig. 53g : Dispersal by Water : Lotus, *Nelumbo nucifera*.

injury. Such type of floating devices is also seen in *Areca catechu* and *Nipa fruticans*, 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.

6.9.3 Dispersal by animals

Dispersal by means of human beings and other animals such as grazing cattles, birds, etc. is by no means infrequent. So, 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 outgrowth of prickly bodies on the pericarp of *Xanthium strumarium*, *Triumfetta bartramia* *Urena lobata*, etc. (Fig. 54a,b).

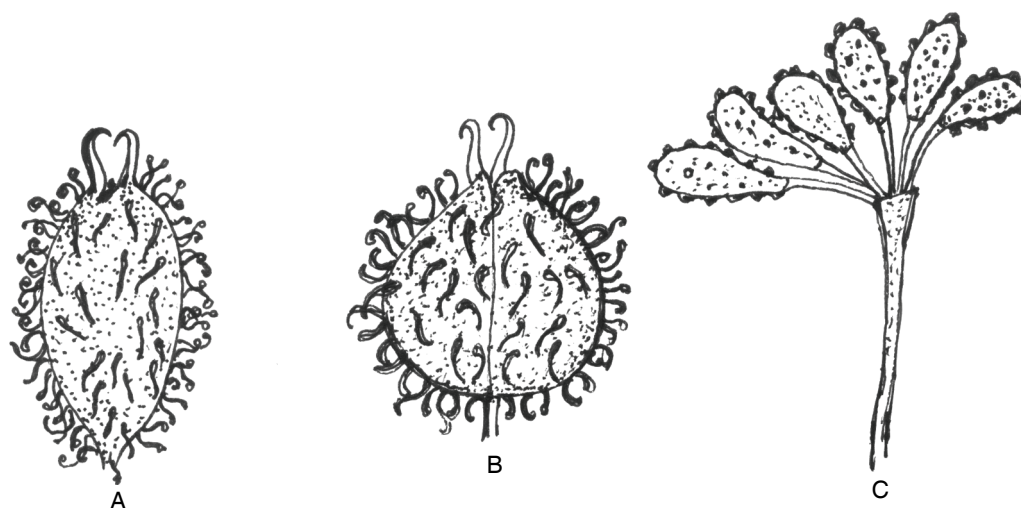


Fig. 54 : Dispersal by animals : A. By spines in *Achyranthes*, B. in *Xanthium*, C. in *Urena*

The fruits provided with spines become attached to the body of animals including human beings and dispersed at distant places, as in 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 distance. Sharp rigid spines on the fruits of *Tribulus* sp. help in dispersal when those get embedded into the foot of hooved 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, flying foxes are found in succulent berries, syconus, etc. The seeds of such fruits have resistant thick testa. The fruits are eaten by birds, the seeds remain undigested in the intestine and excreted off, where they germinate. The growth of *Ficus benghalensis* in the old buildings is due to such mode of dispersal by birds.

6.9.4 Dispersal by explosive mechanism

Explosive and dehiscence mechanism of capsules of many plants are the means of dispersal of seeds to a certain distance. The fruits of *Impatiens balsamina* and *Oxalis* sp. when touched burst with sudden jerk and a little sound; as a result the seeds are scattered to a distance (Fig. 55a). The ripe fruits of *Abrus precatorious* *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 the seeds remain attached with hook like projection known as jaculators or retinacula, which helps in dispersal of seeds to a distance for the member of Acanthaceae..

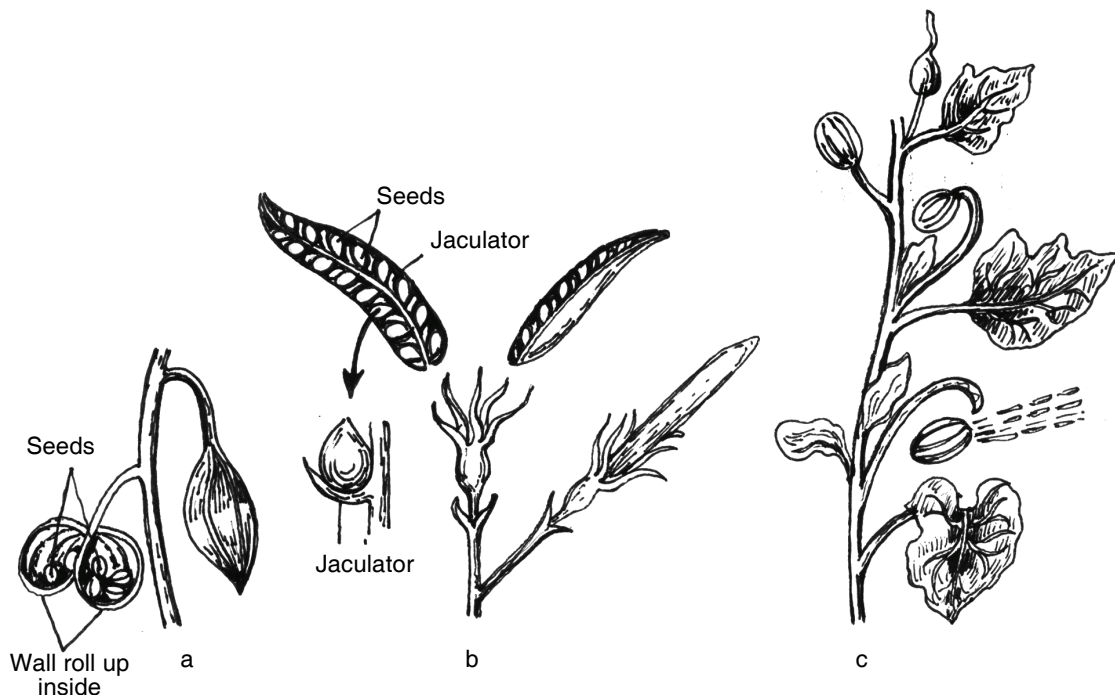


Fig. 55 : Dispersal by explosive mechanism : a. in *Impatiens balsamina*, b. in *Ruellia tuberosa*, C. in *Feballium elaterium* showing dispersal of seed like a fountain

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

6.10 Summary

From the foregoing study the knowledge related to pollination mechanism, adaptations for self and cross pollination can easily be understood. Double fertilization process; seed structure appendages and their mode of dispersal mechanism, etc. can also be ascertained.

6.11 Questions

1. Describe the method of pollination in the following flowers :
(a) *Calotropis*, (b) *Ficus*, (c) any orchid
2. Define autogamy. Give an account of adaptations favouring self-pollination of flower.
3. Define allogamy. Give an account of adaptations for cross pollination.
4. Distinguish fertilization and double fertilization. Define fertilization. What is meant by mesogamy? Describe the process of double fertilization met in angiosperm with suitable illustration.
5. Define seed. Describe different structures of seeds.
6. Describe the mechanism of dispersal of fruits and seeds through different agencies with examples.
7. Mention different agents by means of which seed and fruits are dispersed. State as how the following seeds are dispersed— (a) *Moringa*, (b) *Alstonia*, (c) *Hiptage*, (d) *Gossypium*, (e) *Nymphaea*, (f) *Cocos nucifera*, (g) *Xanthium*, etc.

6.12 Answers

1. See article no. 6.3
2. See article no. 6.2 & 6.4
3. See article no. 6.2 & 6.5
4. See article no. 6.6
5. See article no. 6.7 & 6.7.1
6. See article no. 6.9
7. See article no. 6.9

Unit 7 □ Embryo and Endosperm

Structure

- 7.0 Objective**
- 7.1 Introduction**
- 7.2 Types of endosperm**
- 7.3 Structure and functions of endosperm**
- 7.4 Mosaic endosperm**
- 7.5 Embryo of dicot and monocot**
 - 7.5.1 Development of embryo in dicot**
 - 7.5.2 Development of embryo in monocot**
- 7.6 Embryo-endosperm relationship**
- 7.7 Summary**
- 7.8 Questions & Answers**
- 7.9 Answers**

7.0 Objective

From this study knowledge can be gathered regarding the development of both dicotyledonous and monocotyledonous embryos. In addition to this different form of endosperm formation and the role of endosperm in growing embryo as well as embryo-endosperm relationship can also be understood.

7.1 Introduction

After fertilization, the fertilized egg is called zygote or oospore which develops into an embryo. The oospore before it actually enters into the process undergoes a period of rest. Generally the zygote i.e. 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 zygote is always followed

by a wall-formation resulting in a two-celled proembryo. Practically there are no fundamental differences in the early stages of the development of the embryos of monocot and dicots. But in later stages there is a marked difference between the embryos of dicotyledonous and monocotyledonous plants.

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 polyploid endosperms are also known. Generally the endosperm nucleus divides after the division of oospore but in many cases endosperm is formed even before the first division of oospore.

7.2 Types of endosperm

There are three general types of endosperm formation and these are named such 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 being pushed towards 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. the 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 towards the centre or from its apex towards 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 other 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. This type 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 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).

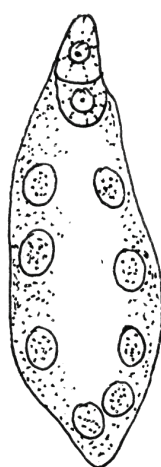


Fig. 56

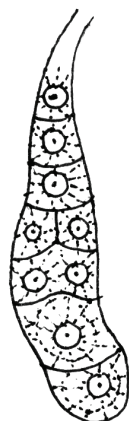


Fig. 57

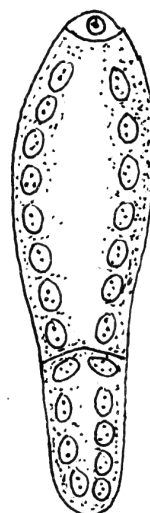


Fig. 58

Fig. 56 : Development of endosperm; Nuclear type

Fig. 57 : Cellular type

Fig. 58 : Helobial type

7.3 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 produced thin-walled cells towards innerside. These cells remain filled with starch. After sometimes 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 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 fill 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 angiosperm the endosperm forms after fertilization and is triploid in nature. In gymnosperms the endosperm forms before fertilization and is haploid in nature.

7.4 Mosaic endosperm

In some angiosperms, there is the lack of uniformity in the tissues of the endosperm, which is termed as mosaic endosperm. For example, in *Zea mays*, the 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 most reasonable explanation for the development of mosaic endosperms. According to them there is either aberrant

behaviour of the chromosomes in mitosis or there are somatic mutation which explain the problem.

7.5 Embryo of dicot and monocot

After fertilization the fertilized egg is called 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 the development show free nuclear divisions the first division of zygote is always followed by a wall-formation resulting in a two called proembryo. Practically there are no fundamental differences in the early stages of the development of the embryos of monocots and dicots. But in later stages there is a marked difference between the embryos of dicotyledonous and monocotyledonous plants.

7.5.1 Development of embryo in dicot

... *Capsella bursa-pastoris* of the family Brassicaceae is considered as the typical example to study the development of dicotyledonous embryo.

Initially at the time of development of embryo zygote divides transversely to form two celled structure, of these two cells, innermost one is termed as terminal cells and the outermost is the basal cell (Fig. 59).

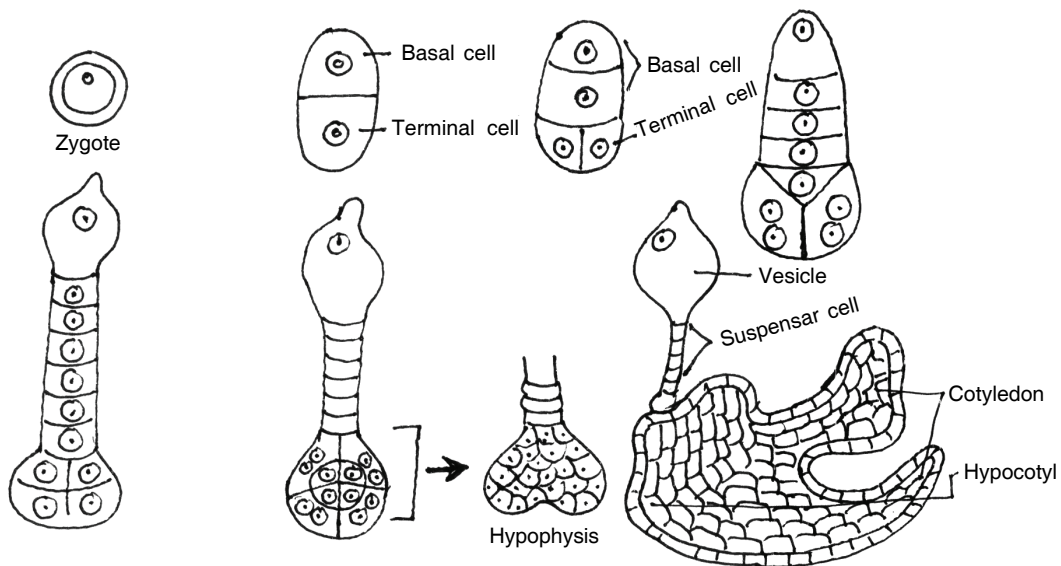


Fig. 59 : Stages in the development of a typical dicot embryo in *Capsella bursa-Pastoris*

Basal cell then divides transversely to form two celled structure. The Terminal cell also divides vertically once. Thus a collection of four-celled structure is formed and looks like inverted 'T'. This is collectively termed as proembryo.

After this each cell out of the two terminal cells divide transversely first and then again divides transversely at its right angle and by this quadrant of 4 cells is formed.

This quadrant further divide transversely to produce octant. 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 hypocotyle along with inner core of the radicle is formed.

In the meantime two basal cells of the proembryo divide repeatedly to form multilayered suspensor cell. Topmost cell of the suspensor forms vesicle by swelling, which acts as suspensor (haustoria) and the Towermost cell act as hypophysis.

Epidermis, cortex and root cap of radicle are formed by the division of hypophysis. In the next stage the development of embryo takes place freely and embryo takes the shape of a heart.

After this through overlapping cell divisions two cotyledons are formed by the elongation of two apical segments of heartshaped embryo and remain as hypocotyl.

Suspensor cell helps in holding the embryo with in the nucellus. The nucellus degenerates with the maturity of embryo.

7.5.2 Development of embryo in monocot

There is no essential difference between development of embryo of the monocotyledonous and dicotyledonous plants regarding the early cell divisions of the proembryo, but the mature embryos are quite different in 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 the terminal cell and the basal cell. The basal cell, is the larger one and lies towards the micropylar end and does not divide again but becomes transformed directly into a large vesicular cell. The terminal cell divides transversely forming the two cells. Of these, the lower cell divides vertically forming a pair of juxtaposed cells and the middle cell divides transversely into two cells. In the next stage the two cells further divide vertically forming quadrants. The cell next to the quadrants also divides vertically and the cell next to the upper vesicular cell divides several times transversely forming 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 after wards develop into a single terminal cotyledon. The lowermost cell of the three-celled suspensor divides vertically to form the plumute or stem tip. The cells below the suspensor form the radicle. The upper 3-6 cells contribute to the form action of suspensor (Fig. 60).

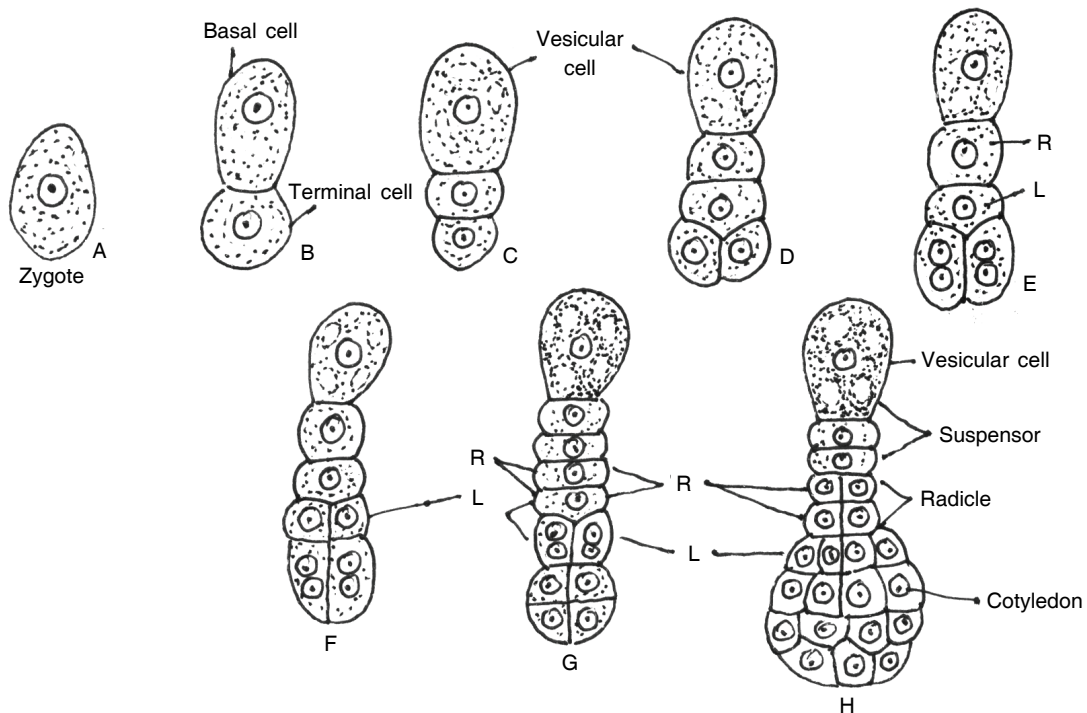


Fig. 60 : Stages in the development of a typical dicot embryo in *Capsella bursa-Pastoris*

7.6 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 egg nucleus (n) with a male nucleus (n), which give rise to embryo, the cells of which are diploid ($2n$). One of the male gamete fuses with the secondary or fusion nucleus i.e. definitive nucleus ($2n$) to produce triploid ($3n$) endosperm nucleus, from which endosperm is formed. This endosperm supplies nourishment to the growing embryo. The ovule together with embryo and endosperm

as a whole give rise to seed which remains covered by the seed coat developed from the integuments.

7.7 Summary

Form the study 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. 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.

7.8 Questions

1. Describe briefly the formation of helobial and cellular endosperm.
2. Write notes on nuclear endosperm and embryo-endosperm relationship.
3. Define embryo. With suitable illustration describe development of typical dicot embryo.
4. With suitable illustration describe development of monocot embryo.
5. Write notes on the function of endosperm and mosaic endosperm.

7.9 Answers

1. See article no. 7.2
2. See article no. 7.2 & 7.6
3. See article no. 7.5 & 7.5.1
4. See article no. 7.5.2
5. See article no. 7.3 & 7.4

Unit 8 □ Apomixis and Polyembryony

Structure

8.0 Objective

8.1 Introduction

8.2 Apomixis

8.3 Parthenocarpy

8.4 Polyembryony

8.5 Summary

8.6 Questions

8.7 Answers

8.0 Objective

Study of apomixis gives a better idea in relation to the formation of plants by substituting normal sexual cycle. Here, sexual reproduction is substituted by an asexual process which does not involve any nuclear fusion.

In this unit knowledge related to true and false polyembryony along with cleavage polyembryony formation technique can easily be understood.

8.1 Introduction

During normal sexual cycle, fertilization leads to the formation of embryo and later on seed. New plants are produced by the germination of seeds. Later on 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 alternation of generations.

However, in many plants the normal process of sexual reproduction is substituted by an asexual process. This phenomenon of substitution of sexual process by asexual process is known as apomixis and the plant which shows this is called as 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 embryo sac other than the egg;
- (c) Embryos developing from cells outside embryo sac; and
- (d) Embryos originating from other embryo sacs in the ovule.

8.2 Apomixis

In many plants normal process of the sexual reproduction is substituted by an asexual process. So the phenomenon of substitution of sexual process by asexual method is known as apomixis. The plant which shows this phenomenon is called as apomictic plant.

The term 'apomixis' was coined by Winkler (1908) and accordingly apomixis may be defined "as the substitution of sexual process which does not involve any nuclear fusion." So in case of apomixis asexual method of the formation of embryo takes place instead of normal production by fertilization.

According to Maheswari (1950) apomixis may be subdivided into 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 as the haploid plants and generally sterile and do not reproduce sexually any more.

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. embryo sac is diploid i.e., all the nuclei of the embryo sac contain diploid ($2n$) chromosomes as there is no reduction division in the number of chromosome. 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 and *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 but they arise only from the cells of 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 *Hiptage madablata*.

- (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, into new plants. As this type is merely a form of vegetative reproduction so this type is not considered as apomixis by many workers.

Bulbils have been reported in *Globba bulbifera*, *Allium sativum*, *Dioscorea bulbifera*, *Agave* sp., *Oxalis* sp., etc.

8.3 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, pine apple, papaw, *Thalictrum*, *Alchemilla*, etc.

8.4 Polyembryony

The 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 embryos are formed in the same embryo sac of the ovule. On the other hand in false polyembryony more than one embryos arise in different embryo sacs in the ovule.

According to Gustafsson (1946) the 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 with in *Nymphaea advena*, *Empetrum nigrum*, *Nicotiana rustica*, etc.

- (b) Origin of embryos from cells of the embryo sac other than egg.
(c) Origin of embryo from cells outside embryo sac.
(d) Origin of embryos from other embryo sacs in the ovule.

8.5 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.

8.6 Questions

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

8.7 Answers

1. See article no. 8.4 & 8.2
2. See article no. 8.4 & 8.2

Further Readings

- Carlquist, S. 1961. Comparative Plant Anatomy Holt, Rinehart and Winston, New York.
- Cutter, E.G. 1971. Plant Anatomy. Part I : Cells and Tissues. Edward Arnold, London.
- Eames, A.J. and Macdaniels, L.H., 1947. An Introduction to Plant Anatomy. McGraw-Hill, N.Y. and London.
- Esau, K., 1965. Plant Anatomy. Wiley, New York.
- Fahn, A., 1987. Plant Anatomy. Pergamon Press. Oxford.
- Gangulee, H.C., Das, K.S. and Dutta C.T. 1968. College Botany. Vol. I. 4th ed. Books and Allied Private Ltd. Calcutta.
- Jatindra Nath Mitra, Debabrata Mitra, Salil Kumar Chaudhuri : Studies in Botany Volume-I, Moulik Library, Kolkata-700073.
- Kashinath Bhattacharya, Gopinath Hait, Ashim Kumar Ghosh. 2007. A Text Book of Botany. Volume II. New Central Book Agency (P) Ltd. Kolkata-700009.
- Pandey, B.P., 1978. Plant Anatomy. S. Chand & Company Ltd., New Delhi, New Delhi-110055.
- Pandey, B.P., Simplified Course in Botany. S. Chand & Company Ltd., New Delhi-110055.
- Roy, Pijush, Plant Anatomy. New Central Book Agency (P) Ltd. Kolkata-700009.
- Tayal, M.S., 1994. Plant Anatomy Rastogi Publications, Meerut.
- Trease, G.E. and Evans, W.C., 1983, Pharmacognosy, 12th Ed., Bailliere Tindall, Eastbourne, U.K.
- Tyler, V.C., Brady and Robbers, T.E., 1981, Pharmacognosy, 8th Ed., Lea and Febiger, Philadelphia.
- Wallis, T.E., Test Book of Pharmacognosy, 5th Ed., J & A Churchill Ltd., London.
- Youngken H.W., 1950. Text Book of Pharmacognosy 6th edition Philadelphia Blackiston.

