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Anatomy of Flowering Plants

Introduction

- Anatomy is the branch which deals with the study of **gross internal structure** of plant organs as observed after section cutting. Study of this branch started in 1671, when **Marcello Malpighi** and **Nehemiah Grew** independently studied the anatomy of vegetable plants.
- **Nehemiah Grew** is known as **'Father of plant anatomy'**.
- **K.A. Chaudhary** is known as **'Father of Indian plant anatomy'**.

TISSUE

- A group of similar or dissimilar cells having a common origin and performing a similar function.
- The term tissue was coined by **Nehemiah Grew**.

TYPES OF TISSUES

- Tissues may be classified into two groups:
  A. Meristematic tissues
  B. Permanent tissues

A. MERISTEMATIC TISSUES (MERISTEMS)

- The term **meristem** has been derived from a Greek word **meristos** - which means **divisible** or having cell division activity, so meristem is a **group of cell which has power of continuous division**.
  e.g.; meristem at apex of stem, root and vascular cambium, etc.
- The term **meristem** was given by **C. Nageli** (1858) for group of continuously dividing cells.
- In multicellular organisms, growth is limited to specific regions. These areas are called meristems.
- The cells of meristematic zone are capable of division until death.

The characteristics of meristematic cells are as follows:

- The cell of meristematic tissue are always **living** and found in **vegetative regions** of the plant. They have thin walls of **cellulose**. Cells are normally **isodiametric, oval, polygonal** or **rectangular**.
- **Abundant cytoplasm** is present. Cells are **compactly arranged** and **lack intercellular spaces**.
- Cells have the **capacity to divide**.
- Vacuoles are either **absent** or **very small**. Large prominent **nucleus is present**. They have no reserve food material and further no ER and plastids in them.

CLASSIFICATION OF MERISTEMATIC TISSUE

Meristematic tissues may be classified on the basis of:

(a) Origin and development
(b) Position in the plant body
(c) Plane of division
(d) Functions

(a) Meristems based on origin and development

On the above basis meristems

(i) **Promeristem (= primordial meristem) :** A group of cells which represent primary stages of meristematic cells. They are present in a small region at the apices of **shoots** and **roots**. They give rise to **primary meristems**.

(ii) **Primary meristem :** The meristematic cells that originate from promeristem are **primary meristems.** These cells are always in **active state of division** and give rise to **primary permanent tissues**. In most **monocots** and **herbaceous dicots**, only primary meristem is present.

(iii) **Secondary meristem :** They are the meristems developed from **primary permanent tissue**. They are not present from the very beginning of the formation of an organ but develop at a later stage and give rise to **secondary permanent tissues**.

Examples: Cambium of roots, interfascicular cambium of stem and cork cambium.

⊠ Secondary growth occurs due to the activity of these cells. It increases the thickness of the plant parts. It is generally found in shrubs and trees.

(b) Meristems based on position in plant body

On the basis of position, the meristematic tissues can be divided into the following three types:

(i) **Apical meristem :** It is found at the **apex** of growing points of root and shoot. It **divides continuously** and brings about growth in length of shoot and root. The apical meristem includes **promeristem** as well as **primary meristem**.

(ii) **Intercalary meristem :** It is present away from apical meristem. It is present at the **base of internodes** e.g.; in grasses and wheat (Gramineae) or at the **base of leaves** e.g.; in Pinus or at the **base of nodes** e.g.; mint or Mentha (Labiatae). It is responsible for **increase in length**.

(iii) **Lateral meristem :** They are located **parallel to the long axis** of the plant organs. Their activity results in **increase of the diameter** of the plant organs. e.g.; **Cork cambium** and **Vascular cambium**.

(c) Meristems based on plane of division

It includes three types of meristems:

(i) **Mass meristem :** In this cell division occur in **all planes** so that an irregular shaped structure is formed e.g. endosperm.

(ii) **Plate meristem :** It consist of parallel layers of cell which divide **anticlinally** in **two planes** so that a **plate-like structure** formed. This pattern is seen in the development of leaf lamina.

(iii) **Rib meristem or File meristem :** In this type, cells divide at **right angles** or **anticlinally** in one plane. It is found in the development of lateral roots.

(d) Meristems based on function

Haberlandt (1980) recognized three categories of apical meristem. It is as follows:

(i) **Protoderm :** It is the **outermost layer** of the young growing region which develops the **epidermal tissue system**.

(ii) **Procambium :** It is composed of **narrow, elongated cells** that give rise to the **vascular tissue system**, that is, xylem and phloem.

(iii) **Ground meristem :** It consists of large, **thin-walled cells** which develop to form **ground tissue system**, that is hypodermis, cortex and pith.

Shoot Apex Organization

- According to **Foster, Gifford** and **Clowes** "Shoot apex is portion of shoot above the youngest primordium". It is present at the **plumular tip** or at the **end of the leaf**. It is covered by young leaves and is visible on removing them. The apex is **dome shaped**.

Theories of Shoot Apex Organization

Different theories have been given:

A. Apical Cell Theory

⊠ This theory was proposed by **Nageli** and **Hofmeister**. According to this theory, a single apical cell is the structural and functional unit of apical meristem.

- This cell cuts off 1, 2 or 3 cells towards the posterior side and forms tissues of the plant body.
- This theory is applicable only to some higher **algae, bryophytes** and **vascular cryptogams** (pteridophyta) and is not applicable to phanerogams (gymnosperms and angiosperms) i.e.; seed plants.

B. Histogen Theory

- This theory was given by **Hanstein (1870)**.
- According to him, shoot apex has three zones, which are called **histogens**. They are of the following types. **Dermatogen** (outermost): Gives rise to **epidermis. Periblem** (middle) : Gives rise to **cortex** including **endodermis. Plerome** (innermost) : Gives rise to **vascular tissue** including **pith**.
- This theory has been rejected as **histogen layers** have not been observed in **gymnosperms** and **angiosperms**.

C. Tunica - Corpus Theory

The proposer of this concept was Schmidt (1924). According to him shoot apex has two region :

(i) **Tunica :** It is generally **single layered** outer region. It divides only **anticlinally**. In **multilayered tunica**, the outermost layer forms the **epidermis** and rest of the layers from **cortex** and **leaf primordia**. Its cells are **small**.

(ii) **Corpus :** The inner mass of cells is called corpus. It divides both **anticlinally** as well as **periclinally**. Its activity results in the formation of **cortex** and **stele**. The cells of corpus are **larger** and divide to result into **increase in volume**.

Root Apex Organization

- Root apex is having simplest organization as compared to shoot apex.
- Root apex is **subapical** or **subterminal** in position because there is present **root cap (calyptrogen)** at the **apex**.

Different theories of root apex organization have been given as :

A. Apical Cell Theory

- Given by **C. Nageli (1878)**. According to this, there is single tetrahedral apical cell in the root apex. This theory is applicable to **pteridophytes** and **gymnosperms** and **not to angiosperms**.

B. Histogen Theory

- Given by **Hanstein (1870)**. According to him, like shoot apex, histogen layers are found in the root apex region. It is of following types:

(a) **Dermatogen :** It gives rise to **epiblema** or **rhizodermis**.

(b) **Periblem :** It gives rise to **cortex** including **endodermis**.

(c) **Plerome :** It gives rise to **vascular tissue** including **pith**.

(d) **Calyptrogen :** It gives rise to the **root cap** in monocots.

Quiescent Centre Concept

- Given by **Clowes (1956)** in **maize**.
- According to this, there is an inactive centre in the root apex which is called **quiescent centre** (having low DNA, RNA and proteins) and it acts as reservoir of active initials.

C. Korper-Kappe Theory

- Given by **Scheupp (1970)**. According to him, the cells of root apex divide first by **transverse wall** and then one of the cells divides by **vertical wall**. According to this theory Korper forms body and kappe forms cap.

B. PERMANENT TISSUES

- It is formed due to **division** and **differentiation** in meristematic tissue. The cells of this tissue may be **living** or **dead, thin-walled** or **thick-walled**. The thin walled tissues are generally **living** whereas the thick-walled tissues may be **living** or **dead**.

Permanent tissues can be of three types :

(a) Simple tissue

(b) Complex tissue

(c) Special tissue

A. Simple Tissues

- These are homogeneous in nature and are composed of structurally and functionally similar cells.

  These are of three types :

  (i) Parenchyma

  (ii) Collenchyma

  (iii) Sclerenchyma

(i) Parenchyma

- Parenchyma is considered as the **precursor** of all other living tissues. It is also the most **primitive tissue** from phylogenetic point of view. Parenchymatous cells are **living, thin-walled,** containing **distinct nuclei**. The cell walls are made up of **cellulose, hemicellulose** and **pectic** materials.
- Cells have **small** or **large** intercellular spaces.
- Cells are generally **isodiametric** (but may also be elongated, lobed and polygonal).
- All meristems made up of **parenchyma**.

  Functions:

  - Parenchyma cells are the centres of **respiration, photosynthesis, storage, secretion**, etc.
  - These cells may have the **power of division**.
  - These cells help in **wound-healing** and in formation of **adventitious buds** and **roots**.
  - Parenchymatous cells store water in **succulent plants**.
  - In aquatic plants parenchyma cells store air and provide **buoyancy to plants**.
  - Parenchyma cells of xylem and phloem help in **conduction of water** and **food materials**.

Specialized Parenchyma

A. **Prosenchyma**

- Parenchyma cells are **elongated**. Found in pericycle of roots.
- Its function is to provide **strength**.

B. **Chlorenchyma :** When parenchyma cells contain chloroplasts, it is known as **chlorenchyma**. **Examples** - leaf mesophyll tissue, outer cortex of young stem, outer cortex of xerophytic stem etc. Its function is to manufacture **food material (photosynthesis)**.

C. **Aerenchyma : In hydrophytes**, the parenchyma develop air spaces and such parenchyma with **air cavities** is known as **aerenchyma**. **Examples** - *Hydrilla* and *Eichhornia* etc. It helps hydrophytes **to float** and **provides O_2 for respiration**.

D. **Idioblast :** In this type of parenchyma non-living ergastic substances like tannins, oil, crystals etc. are found in stored form e.g.; **under ground parts**. Its function is to **store ergastic substances**.

E. **Mucilaginous parenchyma :** It has large **vacuoles** and **mucilage** e.g. **Succulents**. Its function is **storage of water**.

(ii) Collenchyma

- Collenchyma word was given by **Schlieden** (1839).
- These are **living elongated cells** with **thick walls**. The cell wall is made up of **cellulose, hemicellulose** and **pectic materials**. The wall thickening is not uniform.
- The walls are often provided with **simple pits**.
- Sometimes chloroplasts are present in collenchyma cells.
- Collenchyma is found in many **herbaceous dicot stems, petioles** and **younger regions of woody stems**. Collenchyma is **absent in roots** and **monocot stems**.

  Types of collenchyma

  On the basis of thickening on cell wall, collenchyma may be of three types :

  A. **Angular**

  - The deposition is maximum at the angles (where the two cell walls come in contact). The cells appear **polygonal** in **transverse section**.
  - It is the most common type, e.g.: *Tagetes, Lycopersicon*

B. **Lacunar :** Large **intercellular spaces** occur between the cells. The deposition occurs on the walls towards the spaces. The hollow thickened components are found e.g. *Cucurbita.*

C. **Lamellar :** The deposition occurs on **tangential walls**. The cells appear **plate like** or **lamellar**. It is also called **plate collenchyma** e.g.: *Helianthus.*

Functions

- It performs both **mechanical** as well as vital types of functions. Collenchyma provides **tensile strength** which gives elasticity and support to the growing organs. Chloroplast containing collenchyma performs **photosynthetic function.**

(iii) Sclerenchyma (Greek : Scleras = hard)

- The word sclerenchyma was coined by **Mettenius.**
- They are **dead cells**, and act as **purely mechanical**. The cells are **long, narrow** and **pointed** at both ends. The cell walls are **lignified** and have **simple pits.**
- The cell walls are very **thick** with the result that the cell cavity becomes **narrow**.

Types of Sclerenchyma :

It is of two types:

A. Fibres or sclerenchymatous fibres

B. Sclereids or stone cells

A. **Fibres or sclerenchymatous fibres**

- Cells **long, narrow** and **thick walls, pointed at both ends** and **lignified.** Cell wall has **simple** or **bordered pits**. These are unthickened areas.
- Generally length of the fibres is upto **3 mm** but in some cases like **jute** (*Corchorus capsularis*), **Flax** (*Linum*) and **hemp** (*Cannabis*), fibres are upto **20 - 550 mm** in length.
- The fibres present outside xylem are called **extra-xylary fibres**. They are of three types:
  (i) **Cortical fibres** in cortex.
  (ii) **Pericyclic fibres** in pericycle.
  (iii) **Phloem fibres** in phloem.
- Pericyclic fibres are also called **perivascular fibres**. Phloem fibres are also called **bast fibres**.
- Hard fibres
- Soft fibres
  (a) Hard fibres : The hard fibres are **monocot leaf** fibres with very thick lignified walls e.g.; *Yucca, Agave* etc.
  (b) Soft fibres : The soft fibres are **bast fibres** e.g.; Hemp, Flax, Jute, etc.

B. **Sclereids**

- The word was coined by **Tschierch (1885)**.
- These are not much longer than their breadth. They have also extremely thick wall of lignin with narrow lumen. The cells have no **definite shape.**

Types of sclereids

(a) Brachysclereids or **Grit cells** or **Stone cells**

- These are **small, oval** or **rounded** cells. They are found **in cortex, phloem** and **pith of stems** and **fleshy pericarp of certain fruits** (e.g. pear, apple, guava).
- Stone cells are also present in **hard parts** like **endocarp of coconut and hard seed coats.**

(b) Macrosclereids or **Malpighi cells :** These are **rod - like** or **columnar cells**. They are common in the seed - coats of many **leguminous plants** (e.g. pea).

(c) Osteosclereids : These are **barrel - shaped cells** and look like as **bones**. They are found in leaves and seed-coats of several **monocotyledons**.

(d) Asterosclereids : These are **star shaped** cells. They are found in the petioles of Nymphaea.

(e) Trichosclereids: These are **hair - like, branched** or **unbranched cells**. They are found in the **intercellular spaces of leaves** and stems of some aquatic plants.

- **Sclereids provides mechanical strength to the part of the plant where they are present. They contribute to the firmness and hardness of the part concerned. Develops resistance in plant against unfavourable conditions.**

B. COMPLEX TISSUES

- The complex tissues are made up of **living** and **non-living cells** which perform different functions. The complex tissues act as single units. The complex tissues are also known as **vascular tissues**.
- They are of two types: **Xylem** and **Phloem**.

(i) Xylem or wood or Hadrome

- ⊠ Xylem word was given by **Nageli (1858)**.
- ⊠ It is also called as **wood** because the major part of stem and root in vascular plants is costituted by xylem. The function of xylem is to **conduct water** and **mineral salts** upwards from the **root to the leaf** and to give **mechanical strength** to the plant body.
- ⊠ It is a **conducting tissue** and is composed of four different kinds of elements:
  - (a) Tracheids
  - (b) Vessels
  - (c) Wood fibres
  - (d) Wood parenchyma

(a) Tracheids

- ⊠ This word was coined by **Sanio** in **1863**. A single tracheid is highly **elongated** or **tube-like cell** with **hard, thick** and **lignified walls** and a **large cavity**.
- ⊠ The secondary wall layers possess various kinds of thickenings in them and may be distinguished as **annular** (in the form of rings), **spiral, reticulate, scalariform** or **pitted** (simple or bordered).
- ⊠ Tracheids occur alone in the wood of **ferns** and **gymnosperms**, whereas in the wood of **angiosperms** they occur with the vessels.

Functions : These carry out transport of **water, harmones** and **solutes** from the **root to the stem, leaves** and floral parts. It gives **mechanical support** to the plant body.

(b) Vessels

- ⊠ A vessel is a **long, cylindrical, tube-like structure** with **lignified walls** and a **wide central cavity**. The cells are **dead** and **without protoplast**.
- ⊠ These are arranged in **longitudinal series** in which the **transverse walls** (the end plates) are perforated and as such the entire structure looks like a **water pipe**. The perforations may be **simple** (only one pore) or **multiple** (several pores).
- ⊠ Vessels also have various type of thickenings similar to tracheids.
- ⊠ Vessels are found only in some **pteridophytes** (e.g. *Pteridium, Selaginella*) and **gymnosperms** (e.g. *Ephedra, Gnetum*). However they are present in almost all angiosperms.
- ⊠ Vessel less angiosperms are *Trochodendraceae, Tetracentraceae* and *Winteraceae* members.

Functions : They serve as a **more efficient** mode of **transport of water** and **minerals** as compared to tracheids due to the presence of **perforation plates**. These also give **mechanical support** to the plant body.

(c) Xylem fibres (Wood fibres)

- ⊠ Sclerenchymatous cells associated with xylem are called **xylem fibres**. They are **long, narrow, thick** and **lignified cells**; usually pointed at both ends. Xylem fibres are **dead cells**.
- ⊠ Xylem fibres are of two types :
  1. Libriform fibres
  2. Fibre tracheids

1. **Libriform fibres** have very **thick walls** and **simple pits**.
2. **Fibre tracheids** have **thin walls** and **bordered pits**.

Functions : Xylem fibres provide **mechanical strength** to the xylem and to the plant body as a whole.

(d) Xylem parenchyma (Wood parenchyma)

- The parenchymatous cells found in xylem are **living** and **isodiametric**. Xylem parenchyma cells are more common in primary xylem than secondary xylem.
- Xylem parenchyma cells of primary xylem are **thin-walled and** made up of **cellulose,** while those found in secondary xylem are **thick-walled** and made up of **lignin**.
- When parenchyma is not associated with vessels, they are **apotracheal parenchyma** and when they are surrounding the vessels are called **paratracheal parenchyma**.

Functions :

- It serves for **food storage.**
- It helps in the **conduction of water upwards.**

(ii) Phloem or bast or Leptome

- The term phloem was coined by **Nageli** (1858).
- Term Leptome was given by **Haberlandt.**
- Phloem is another type of **conducting tissue** like xylem which is responsible for conduction of organic substances. The phloem from the **procambium** is called **primary phloem** and that formed from **vascular cambium** is called **secondary phloem.**

The phloem is composed of four elements:

(i) Sieve tube elements
(ii) Companion cells
(iii) Phloem parenchyma (Bast parenchyma)
(iv) Phloem fibres (Bast fibres)

(i) Sieve tube elements

- Sieve elements were discovered by **Hartig (1837).**
- Sieve tubes are **tube-like structures**, composed of **elongated cells**, arranged in **longitudinal series** and associated with **companion cells**. Their walls are **thin** and made of **cellulose**.
  In a mature sieve tube the nucleus is **absent** but **peripheral cytoplasm** as well as **large vacuole is present.**
- The uniqueness of the sieve tube is that although **without nucleus,** it is living and the **nucleus of the companion cells control its functional activities.**
- The transverse partition walls are perforated by a number of pores, giving the appearance of sieves. They are called the **sieve plates.**
- A sieve plate is called **simple** if it has only **one sieve area**. A sieve plate is called **compound** if it has **many sieve areas.**
- At the end of the growing season the sieve plate is covered by a deposit of **carbohydrate** called **callose**. But in the spring, when the active season begins, it gets **dissolved.** In old sieve tubes callose forms a permanent deposit.
- The **P-proteins** (P=phloem) are seen evenly distributed throughout the lumen of the sieve tube. During wounding, along with callose, **P-proteins help in sealing.**
- In **lower vascular plants** and **gymnosperms** in place of sieve tube elements, sieve cells are present.

Functions : The main functions of the sieve tubes is the transport of prepared food materials from leaves to the storage organs in the downward direction and then to growing regions in the upward direction.

(ii) Companion cells

- These are **specialised parenchyma cells** which are closely associated with the sieve tube elements in their **origin, position** and **function.**
- These originate from the same **meristematic cells** that give rise to the sieve tube elements.
- The companion cell has **dense cytoplasm** and **prominent nucleus.**
- It **nucleus** also controls the metabolic activities of the sieve tube.

(iii) Phloem parenchyma (Bast parenchyma)

- These are **living parenchymatous cells** which may be **cylindrical, sub-spherical** or **polyhedral** in shape.
- The cells have **dense cytoplasm** and **nucleus.**
- The cell-wall is composed of **cellulose.**

(iv) Phloem fibres (Bast fibres)

- These are much **elongated, unbranched** (rarely branched) and have **pointed, needle-like apices.**
- Their cell wall is quite thick with **simple** or **slightly bordered pits. At maturity** these fibres lose their protoplast and become **dead.**
- These occur in **groups** e.g.; in *Linum usitatissimum* (flax) and *Corchorus capsularis* (jute).

Functions :

- The phloem fibres provide **mechanical support to the phloem.**
- The phloem fibres are economically very important as they are used in making cords, gunny bags, and coarse cloth.

C. Special Tissues or Secretory Tissues

These tissues perform special function in the plants e.g.; secretion of resin, gum, oil and latex.

These tissues are of two types:

(i) Glandular tissue

(ii) Laticiferous tissue

(i) Glandular tissue

- It consists of glands and a gland is **specialized group of cells**, capable of secreting some substances.

These glands are further of two types:

(a) External glands

(b) Internal glands

(a) External glands : These generally occur on the epidermis of stem and leaves as glandular outgrowth e.g.; glandular hair, nectar secreting and enzyme secreting glands.

1. **Glandular hair**
   - These hairs are present in **epidermal layers of leaves** and are of various kinds.
   - Contents of hair are **poisonous** and are secreted by a gland at the base of hair.
2. **Nectaries**
   - Present in **flowers** or **leaves.**
   - Cell walls of these cells are **thin** and the cells have **dense cytoplasm.**
3. **Digestive glands** or **Enzyme secreting glands : Insectivorous plants** possess the power of **digesting proteins** from bodies of insects by secreting some digestive enzymes by means of glands or glandular hair. e.g.; *Nepenthes, Drosera* (sundew).

(b) Internal glands

- These glands are found **inside the plant.**
- These glands are **spherical** or **tubular.**

Various types of internal glands are as follows:

(i) Oil glands : Lysigenous cavity is formed due to dissolution of glandular cells which contain oil, these are called as **oil glands** e.g.; oil glands in **leaves** and **rind** of the fruits of **Citrus** and **Orange.**

(ii) Mucilaginous glands : Mucilage occurs in **lysigenous cavity**, it is called as **mucilaginous gland.** Example : In leaves of betel vine.

(iii) Resin/Tannin/Gum glands : The glandular cells have **schizogenous cavities** which are filled with resin, tannin or gum. e.g.: **Resin gland** in leaves and stem of ***Pinus.*** **Gum gland** in stem of

(iv) **Water secreting glands :** (Hydathodes = water stomata) These excrete water in the form of **drops** found in leaves of some herbacious angiosperms that generally grow in humid places. Hydathodes are present at the **tip of leaves** of some plants e.g.; *Colocasia* or along **margin** e.g.; *Tropaeoleum.*

(ii) Laticiferous tissue

- This tissue is mainly composed of **thin walled, elongated, branched** and **multinucleate** tube like structures. They contain **colourless, milky** or **yellow coloured juice** called **latex.**
- They are scattered throughout the ground tissue of the plant and contain stored organic matter in the form of **starch, rubber, tannins, alkaloids, mucilage, enzymes, protein** etc. This tissue is of two types:

A. **Latex cells (Non articulated laticifers)**

- They differ from latex vessels in that they are not formed due to cell fusions and with other latex cells to form a network.
- They are **branched** or **unbranched.**
- *Calotropis, Nerium, Thevetia, Euphorbia, Ficus, Catharanthus roseus* etc. contain latex cells.

B. **Latex vessels (Articulated laticifers)**

- They are composed of a large number of cells placed end to end with their transverse walls dissolved so as to form a long vessels. They are unbranched in the beginning but get branched later.
- Two or more latex vessels fuse with each other forming a network e.g.; *Papaver, Argemone, Sonchus.Carica.*

THE TISSUE SYSTEM

TYPES OF TISSUE SYSTEMS

- It was **Sachs,** a **German scientist,** who for the first time in **1875** attempted to classify the tissues on the basis of their **position and morphology.**
- According to him, the following three categories of tissue systems can be distinctly identified.

A. The epidermal tissue system.
B. The ground or fundamental tissue system.
C. The vascular/conducting tissue system.

A. The Epidermal tissue system

It comprises the following:

(a) **Epidermis**

- The epidermis (**epi** : upon; **derma** : skin) is the **outermost layer** of the plant body, which has direct contact with external environment.
- It is made up of **elongated, compactly arranged cells** which constitute a continuous layer without any intercellular spaces.
- The cells have a **large, central vacuole** surrounded by a thin layer of protoplasm.
- The epidermis may also be **multilayered** as in the **aerial roots of** Orchids and **leaves of** *Nerium* and *Ficus.*
- The outer wall of epidermis is **thick** and usually covered by a **cuticle** formed by the deposition of a **waxy material** secreted in the epidermal cells. **The cuticle is thickest in the xerophytic plants.**
- Some epidermal cells of certain **monocots** (grasses, maize, sugarcane) are comparatively **large,vacuolated** and **thin-walled. These** are called **bulliform** or **motor cells**. These cells **store water** and **help in closing and opening of leaves due to changes in turgor**.
- The epidermal cells of some plants (e.g. *Ficus*) contain crystals of **calcium carbontate** in the form of bunches or grapes. These are called **cystoliths**. The cells containing cystoliths are called **lithocytes.**
- The outermost layer of roots is referred to as **epiblema** or **piliferous layer**. There are **no stomata** and **cuticle** on the epiblema.

(b) **Stomata**

- Stomata are **very small openings** found in the **epidermis** of green aerial parts of the plant especially the leaves

- Pore of each stoma is surrounded by **two kidney shaped** (= semilunar) cells, called **guard cells**. The guard cells are **living** and contain **chloroplasts**. The inner walls are **thicker** than the outer walls.
- The guard cells regulate the opening and closing of the stomatal pores.
- In **xerophytes** the stomata are sunken in grooves due to which **rate of transpiration is greatly reduced.**
- In **some monocots** e.g.; doob grass, maize the guard cells are **dumb-bell shaped**.

(c) **The epidermal appendages**

- In many plants epidermis bears outgrowths, called **trichomes** or **hairs** which vary markedly in their shape, structure and function.
- **Trichomes help in checking excess loss of water (reduction of water loss).**
- **Trichomes help in protection, dispersal of seeds and fruits.**

(d) **Root hair :** The epidermis of roots bears root hair in the specialized region - **the root hair zone**. The root hairs are formed due to the elongation of the epidermal cells and are not **protuberances** or **appendages**. It play an important role in **anchoring** the plant body in the soil besides **absorbing water** and **mineral solution** from it.

B. Ground or fundamental tissue system

- The ground tissue system forms the **main bulk of the plant body**. It includes all the tissues **except epidermis** and **vascular bundles**.
- It is **partly derived** from the **periblem** and **partly** from the **plerome**.
- The primary function of this tissue system is **storage** and **manufacture of food material**.
- This system has different kinds of tissues such as **parenchyma, collenchyma** and **sclerenchyma**; of these parenchyma is most abundant and carries out a variety of functions.
- In **monocotyledonous stem** (with scattered vascular bundles) the ground tissue is **not differentiated** into cortex, pericycle and pith.
- In **dicot stems, dicot roots** and **monocot roots** (in which vascular bundles are in a ring), the ground tissues constitute the following parts:

(a) Cortex
(b) Pericycle
(c) Medulla or Pith

(a) **Cortex :** It can be divided into hypodermis, general cortex and endodermis.

(i) **Hypodermis**

- It is found just **below the epidermis**. It is made up of **collenchymatous cells in a dicot stem** and of **sclerenchymatous cells in a monocot stem.**
- Hypodermis remains **absent in roots.**
- Hypodermis **protects the internal tissues** and **gives mechanical support to the peripheral region.**

(ii) **General cortex**

- This part lies between **hypodermis** and **endodermis**. It is made up of **parenchymatous cells**. Sometimes, the cell contain chloroplasts.
- The cells are **spherical** or **isodiametric** with **intercellular spaces**.
- The cells contain **different types of crystals** and **starch grains**.

(iii) **Endodermis**

- Endodermis is **single layered** structure which separates cortex from stele. Endodermis composed of compactly arranged **parenchyma cells**.
- The cells of endodermis in stem are **barrel-shaped, without intercellular spaces, living** and containing **starch**. (Hence it is known as **starch sheath**).
- **Radial and tangential walls of endodermal cells in root possess thickenings of lignin, suberin** and **cutin** in the form of **strips** or **bands**, which are known as **casparian bands** or

- There are thick-walled and thin-walled cells in endodermis and **thin-walled cells** are known as **passage cells** or **transfusion cells**, which are present **opposite the protoxylem groups.**

(b) Pericycle

- Pericycle is situated in between **endodermis** and **vascular bundles**. The cells of pericycle are **parenchymatous** or **sclerenchymatous**.
- In **dicot stem it is multi-layered** while it is **not distinct in monocot stems.**
- Pericycle is present in most of the roots **except in roots of parasitic plants and hydrophytes.**
- In dicotyledonous stems it occurs as a **cylinder** which encircles the **vascular bundle** and the **pith.**
- In ***Smilax*** **root**, pericycle is **multilayered** and **sclerenchymatous**.
- In **angiosperms**, pericycle gives rise to **lateral roots**.
- In **dicot roots** it gives rise to a portion of the **vascular cambium** and later the whole of **cork cambium.**
- **In stems** it is the **seat of origin of adventitious roots.**

(c) Pith or Medulla

- The pith or medulla is the central core of the stem and the root. It is usually made up of **large parenchyma cells** with **intercellular spaces**.
- In the **dicot stem** the pith is **large** and **well-developed.**
- In the **monocot stem**, due to scattered distribution of vascular bundles, it is **absent.**
- In the **dicot root pith is either small** or **absent**, while in the **monocot root a distinct pith is present.**
- In the **dicot stem** the pith extends towards the pericycle between the vascular bundles. The extensions are called **pith** or **medullary rays** which are made up of **parenchyma cells.**
- Medullary rays are not present in the **roots**.
- The function of the pith is to store various substances such as starch, mucilage, tannin, etc.

C. Vascular tissue system

- Central column of axis (root and stem) is called **stele**, which is made of number of vascular bundles, which constitute **Vascular tissue system**.
- The vascular bundle is having **xylem, phloem** and **cambium** (if present).
- Xylem may be **exarch** or **endarch**.
- In **roots**, xylem is **exarch** or **centripetal**, i.e.; protoxylem or first formed xylem is towards periphery.
- In **stem**, xylem is **endarch** or **centrifugal**, i.e.; protoxylem is towards centre (pith).
- If the **cambium is present** in between the xylem and phloem are said to be **open vascular bundle** (e.g.; dicots).
- If the **camblum is absent** in between the xylem and phloem are said to be **closed vascular bundle** (e.g.; monocots).

Types of vascular bundle

According to the arrangement of xylem and phloem vascular bundles are of three types:

(a) Radial
(b) Conjoint
(c) Concentric

(a) Radial : When xylem and phloem are arranged in an **alternate manner on different radii**, such vascular bundles are called **radial**. All the roots of plants contains **radial vascular bundle**. The development of xylem in these vascular bundle is **centripetal**. Thus, these vascular bundles are called **exarch**.

(b) Conjoint : When xylem and phloem are present on the **same radius**, this type of vascular bundles are known as conjoint. Conjoint vascular bundles are the characteristic feature of **stem**. Depending upon the **mutual relationship of xylem and phloem**, these are divided into two types:

(i) **Collateral**

- When xylem and phloem lie together on the **same radius**, xylem being **internal** and phloem **external**, such vascular bundles are called collateral.
- A collateral bundle may be **closed** or **open**.
- In this vascular bundle order of development of xylem is **centrifugal** because protoxylem is present in the centre of xylem so **endarch** condition is found.
- This vascular bundle is found in **gymnosperm** and **angiosperm**.

(ii) **Bicollateral**

- These are **two patches of phloem** one on each side of xylem. In such a vascular bundles there are **two strips of cambium** one on each side of xylem. Only outer cambium is functional.
- Bicollateral vascular bundles are found in families **Cucurbitaceae, Solanaceae, Apocynaceae** etc.

(c) **Concentric**

- When xylem surrounds phloem completely or phloem surrounds xylem completely, such vascular bundles are called **concentric**.
- Concentric vascular bundles are **always closed**. They are of two types:

(i) **Amphicribal or Hadrocentric**

- The xylem is in the centre surrounded on all sides by phloem, such vascular bundle is termed **amphicribal** or **hadrocentric** (i.e.; **hadrome** or **xylem** in centre).
- Such types of vascular bundles are found in **ferns** and **lower gymnosperms**.

(ii) **Amphivasal or Leptocentric**

- The phloem is in the centre surrounded on all sides by xylem. Such vascular bundle is termed **amphivasal** or **leptocentric** (i.e.; leptome or phloem in centre).
- Such vascular bundle exceptionally formed in **Angiosperms** e.g. *Dracaena, Yucca* etc.

STELE

- The stele is the whole central mass of vascular tissue with or without pith surrounded on the outer side by endodermis.
- The concept of stele was proposed by **Van Tiegham** and **Douliot in 1886**.
- The stele includes **primary vascular tissues, pericycle** and **pith**. **The steles are of the following types**:

A. Protostele or Monostele

- Protostele is the most **primitive** and **simplest** type of stele. It consist of a solid mass of xylem completely surrounded by phloem. Such type of stele devoid on pith. Solid stele is of following types:

(a) **Haplostele :** In this stele, xylem surrounded by a smooth layer (Some thickness) of phloem.
Examples : *Selaginella kraussiana, Lycopodium cernum.*

(b) **Actinostele : Xylem stellate** i.e.; xylem has radiating rays emerging from centre.
Examples: *Psilotum, Isoetes, Lycopodium serratum.*

(c) **Plectostele :** A such type of solid stele in which the xylem divides into a number of separate plates which lie parallel to one another.
Example: Most of the species of ***Lycopodium***, e.g., *L. Clavatum.*

B. Siphonostele

- Siphonostele is that stele in which the pith is present in the centre of hollow vascular cylinder. It is of two types:

(a) **Ectophloic siphonostele :** Phloem is present outside the xylem.
Examples: *Equisetum, Osmunda.*

(b) **Amphiphloic siphonostele :** Phloem is present on both sides of the xylem.
Examples : *Marsilea, Adiantum.*

C. Solenostele

- A broken siphonostele is called **solenostele.** Vascular tissue going into leaves as **leaf traces** coming out of the main vascular cylinder causes gaps in it called **leaf gaps.** Thus the vascular cylinder gets broken at places.
- It can be **ectophloic** or **amphiphloic.**

Example : In some **ferns.**

D. Dictyostele

- When the production of many leaf gaps in solenostele main vascular cylinder, breaks into many fragments, then such type of solenostele is called **dictyostele.**
- Each divided fragment (piece) is called **meristele.** Each meristele has its own separate endodermis and pericycle.
- Dictyostele is **well developed** type of stele in **Pteridophytes.**

Examples : *Pteridium, Pteris, Dryopteris.*

E. Eustele

- There is a ring of vascular bundles which are separated from each other by medullary rays. Examples : *Equisetum,* Angiosperms (dicots) and Gymnosperms.

F. Atactostele

- Many vascular bundles are distributed in the ground tissue. Such type of stele is called **atactostele.** This is **highly developed** type of stele. Endodermis and pericycle is **absent** in atactostele. Such type of stele is the main characteristic feature of **monocotyledons.**

INTERNAL STRUCTURE OF STEMS, ROOTS & LEAVES

A. Internal Structure of Dicotyledonous Stems

The transverse section of the young sunflower (*Helianthus annus*) stem shows the following structure:

(i) **Epidermis :** Epidermis is the **outermost layer** of stem. It is made up of **single layer of cells** and **lack of chloroplast. Multicellular hair** and **stomata** are found on epidermis.

(ii) **Cortex : It can be divided into three regions:**

(a) **Hypodermis :** It is present just below the epidermis. It is thick **multicellular layer.** This layer is composed of **collenchyma** and their cells contain **chloroplast.** So that hypodermis is **green** and **photosynthetic.**

(b) **General cortex :** This lies internal to the hypodermis and consists of a few layers of thin walled, **parenchymatous cells.** There are **distinct intercellular spaces** in it.

- **Storage of food** is the main function of the cortex.

(c) **Endodermis :** It is **innermost layer** of the cortex. The cells of endodermis are **barrel shaped** and **without intercellular spaces.**

- The endodermis contains numerous starch grains and is also known as the starch sheath.

(iii) **Pericycle :** This layer situated in between the endodermis and vascular bundles (below the endodermis and above the vascular bundle). The pericycle is a **heterogenous layer** made up of both **parenchymatous** and **sclerenchymatous cells.**

(iv) **Vascular bundles :** The vascular bundles are arranged in a **ring** internal to the endodermis. Each vascular bundle is **conjoint, collateral, endarch** and **open.**

(v) **Medullary rays :** A few layers of big, **polygonal cells** lying in between two vascular bundles are the **medullary rays.** These store **water** and **food material,** and also function in **lateral conduction.**

(vi) **Pith (medulla) :** It extends from below the vascular bundles up to the centre and is composed of **rounded** or **polygonal, thin-walled cells** with **abundant intercellular space** in between them. These cells store **food material** and **water.**

INTERNAL STRUCTURE OF MONOCOTYLEDONOUS STEM

- The internal structure of the young **maize** (Zea mays) **stem,** which is a **monocot** shows the following details in a transverse section:

(i) **Epidermis :** This is single **outermost layer** with a **thick cuticle. Multicellular hair** are **absent** and comparatively less ...

(ii) **Hypodermis :** This is formed of **scleren-chymatous cells,** usually **2-3 layers thick**; lying **below the epidermis.**

(iii) **Ground tissue :** The entire mass of **parenchymatous cells** next to hypodermis form **ground tissue.** Like the dicot stem, it is not differentiated into **cortex, endodermis** and **pericycle.**

- The vascular bundles remain **scattered** in the ground tissue.

(iv) **Vascular bundles**

- Many vascular bundles are **scattered** in the ground tissue. Each vascular bundle is **parenchymatous** surrounded by a sheath of **sclerenchymatous cells/fibres** called the **bundle sheath.**
- This sheath is extensively developed at the **upper** and **lower faces of vascular bundles.**
- The vascular bundles are **conjoint, collateral, endarch** and **closed.**
- They are **numerous, smaller** and **densely** arranged towards the periphery but larger and loosely arranged **towards** the centre of the stem.
- Xylem consist of **four distinct vessels,** arranged in the form of **'Y'.**
- A **schizolysigenous cavity** (water-containing cavity), formed by the breaking down of inner protoxylem vessel and the nearby cells.

(v) **Pith and stele**

- **Atactostele** is found in **monocotyledon.** This is **highly developed stele.**
- **Undifferentiated pith** is present in **monocotyledon stems.**

Internal Structure of Dicotyledonous Root

A thin T. S. of **gram** (*Cicer arietinum*) **root** shows the following structure:

(i) **Epiblema :** This is also known as the **piliferous layer.** It is characteristically **single layered,** comprising **tubular living components.** Cuticle and stomata are **absent.** The outer walls of some cells protrude in the form of **unicellular root hair.** These hairs help in **absorption of water** from the soil.

(ii) **Cortex**

- This consists of many layers of thin-walled **parenchymatous cells** with **plenty of intercellular spaces.**
- In some cases, the epiblema soon dies off; a few outer layers of the cortex become **cutinized** and form the **exodermis.**
- The cortical cells store **starch** but in the **aerial roots** of *Tinospora* it contain **chloroplasts** and thus become **green** and **photosynthetic.**

(iii) **Endodermis :** The innermost layer of cortex is the **endodermis** which completely surrounds the **stele.** It comprises a single layer of **barrel-shaped** cells **without intercellular-spaces.** Cells of endodermis have special thickenings called **Casparian strips.** Endodermal cells outside the protoxylem, do not have casparian strips such cells are called **passage cells.**

(iv) **Pericycle :** It is made up of thick-walled **parenchymatous cells. Lateral root** originates from the **pericycle.** Thus lateral roots are **endogenous** in origin. The branches of stem are **exogenous** in origin because, they originate from the outer part of cortex.

(v) **Vascular bundles**

- These are always arranged in a **ring** and are **radial** i.e.; xylem and phloem are situated at different radii. The protoxylem is always away from the centre and metaxylem towards the centre. This condition of xylem is called **exarch.**
- The number of vascular bundle in dicot is 2-6 (diarch to hexarch).
- **Exception:** polyarchic condition is found in *Ficus* (Banyan tree).
- The vascular bundle in **gram root** are **tetrach.**

(vi) **Conjunctive tissue :** The **parenchyma** lying in between xylem and phloem bundles forms the **conjunctive tissue.** Vascular cambium is formed from the conjunctive tissue during the secondary growth.

(vii) **Pith :** It occupies a small area in the centre of the root and consists of parenchymatous cells.

INTERNAL STRUCTURE OF MONOCOTYLEDONOUS ROOT

In a T.S. of the **maize** (*Zea mays*) **root** the following structures are seen:

(i) Epiblema : It is the outermost layer of the root with large number of unicellular hair.

(ii) Cortex : Below the epiblema is present **multilayered parenchymatous tissue** with **intercellular spaces**. It is cortex.

(iii) Endodermis : The **innermost layer** of the cortex is the endodermis. Endodermal cells are **barrel-shaped, without casparian strips** as the whole wall is thickened.

(iv) Pericycle : It is **uniseriate** and is made up of Prosenchyma.

(v) Vascular bundle : Vascular bundles are **polyarch, radial** and **exarch. Phloem parenchyma absent**.

(vi) Conjunctive tissue : It is made up of **parenchymatous cells** in between the xylem and phloem.

(vii) Pith : Large, made up of loosely arranged **parenchymatous cells** with **abundant starch grains**.

INTERNAL STRUCTURE OF DICOT OR DORSIVENTRAL LEAF

The transverse section of a **Mango leaf** shows the following structures:

(i) Upper epidermis : This is the outermost layer made of **unilayered parenchymatous cells** attached to one another. The outer wall of the cells are **cuticularized**. Stomata and chloroplasts are **absent**.

(ii) Lower epidermis : It is a single layer of **parenchymatous cells** with a **thin cuticle**. It contains **numerous stomata**. Chloroplasts are present only in **guard cells**. The lower epidermis helps in the **exchange of gases**. The **loss of water vapour** is facilitated through this chamber.

(iii) Mesophyll : The tissue in between the upper and lower epidermis is called **mesophyll**. This is divided into two regions:

(a) Palisade tissue

- The cells of this tissue are **elongated** forming an **angle of 90°** with the upper epidermis. These cells have **chloroplasts**.
- The cells donot have **intercellular spaces** and they take part in **photosynthesis**.

(b) Spongy parenchyma

- It is found **below the palisade tissue**. The cells of spongy parenchyma are almost **spherical** or **oval** and are irregularly arranged.
- The cells also have **chloroplasts**, and are with **intercellular spaces**.
- Intercellular spaces help in **diffusion of gases**.

(c) Vascular bundles

- It is scattered in **spongy parenchyma**.
- The vascular bundle of **mid-rib is largest**. Vascular bundles are **collateral** and **closed**.
- Around each vascular bundle is present a sheath of **parenchymatous cells** called **bundle sheath**.
- Each vascular bundle consists of xylem lying towards the upper epidermis and phloem towards the lower epidermis.

INTERNAL STRUCTURE OF MONOCOT OR ISOBILATERAL LEAF

(i) Epidermis : The upper and lower epidermis consist of **parenchymatous cells**. They contain more or less an equal number of stomata and are uniformly **thickened** and **cuticularized**. The cells of epidermis **don't possess chloroplast**. Stomata are present on both upper and lower epidermis **(amphistomatic). Guard cells** are the only epidermal cells, which possess **chloroplast**. In the **upper epidermis**, there are some large cells found in groups, which are known as **motor cells** or **bulliform cells**.

(ii) Mesophyll

- The mesophyll is **not differentiated** into palisade and spongy parenchyma.
- These cells are almost **spherical** and enclose **small inter-cellular spaces** and are **irregularly arranged**. These cells contain **chloroplasts**.

(iii) **Vascular bundles :** Large number of vascular bundles are present, some of which are **small** and some are **big**. Around each vascular bundles there is present **bundle sheath of parenchymatous cells**. Above and below larger vascular bundles there are present **patches of sclerenchymatous cells**. Vascular bundles are **conjoint, collateral** and **closed**. Xylem is present towards **upper epidermis** and phloem towards **lower epidermis**.

SECONDARY GROWTH

- **"Secondary growth is increase in girth or diameter of axis (root and stem) of the plant by formation of secondary tissue by activity of lateral meristem** (vascular cambium and cork cambium)."

  The secondary tissue is of two types:
- **Secondary tissue formed by true cambium** or **vascular cambium** or **intrastelar cambium**.

  e.g., Secondary xylem and secondary phloem.
- **Secondary tissue formed by cork cambium** or **phellogen** or **extrastelar cambium**.

  e.g., Phellem or cork cells and phelloderm (sec. cortex).

Secondary Growth in Dicot Stem

A. Secondary growth by Vascular cambium

- The vascular bundles in dicot stem are **conjoint, collateral** and **open** and are arranged in a ring. The cambium present between xylem and phloem in vascular bundles is called **fascicular** or **intrafascicular cambium**.
- Some cells of medullary rays (i.e., between vascular bundles) also become **meristematic** and this is called **interfascicular cambium**.
- Both these cambia collectively constitute a complete ring of **vascular cambium** or **intrastelar cambium**.
- The ring of vascular cambium or true cambium cuts off cells both on **outer side** and **innerside**. The cells cut off on outer side are **secondary phloem** and on inner side are **secondary xylem**.
- Amount of secondary xylem cut off is more than secondary phloem and thus with the formation of secondary tissue, **increase in girth** or **diameter** occurs, which is thus called **secondary growth**.
- Cambium cells are **rectangular, thin-walled, full of protoplasm** and having **meristematic activity**.

  Further cambium cells are of two types:

  <u>**Fusiform initials**</u>

  These are **elongated cells**, which give rise to vertical elements, e.g.; vessels, tracheids, sieve tube element etc.

  <u>**Ray initials**</u>

  - These are horizontal in position, smaller and give rise to rays in secondary tissue.
  - The structure of **secondary xylem** and **secondary phloem** is similar to that of primary xylem and primary phloem. With the increase in secondary tissue, the primary xylem and primary phloem get crushed.

  <u>**Xylem and phloem rays (vascular rays)**</u>

  - At some place the cambium does not form secondary xylem and secondary phloem but form parenchymatous cells instead of xylem and phloem. Thus these cells form continuous strips from secondary xylem to secondary phloem and are called **secondary medullary rays**. These rays are arranged **radially**. Primary and secondary medullary rays conduct **food, water** and **minerals** from centre to periphery.

  <u>**Annual Rings or Growth Rings**</u>

  - There is a marked difference in activity of cambium with change in season. In **spring**, the activity of cambium **is more** and hence the **wood elements are larger in size** with **wide lumen**. Moreover, the amount is more and the secondary xylem or wood formed during spring is called a **spring wood**.
  - The activity of cambium is **less** during **winter** or **autumn** and the **wood elements are smaller in size** with **narrow lumen**. Moreover, it is lesser in amount and the wood formed during winter or autumn is called **winter** or **autumn wood**.
  - Spring wood + Autumn wood of a year constitute **annual ring**.
  - The age of tree can be determined by counting annual rings in oldest or basal portion of tree trunk. **Calculation of age of the tree by counting annual rings is called Dendrochronology**.

Porous and Non-Porous Wood

- The wood of **dicotyledonous trees** in which **vessels are present in the xylem is called porous wood.** It is also known as the hard wood.
- The wood in which **vessels are not found is called non-porous wood**, as in **gymnosperms**. It is also known as the **soft wood**.
- The porous wood is of two types. In some trees **large spring vessels are arranged more or less in a ring**. This type of wood is said to be **ring-porous**. In others, **the vessels have equal diameter and are uniformly distributed throughout the wood**. This wood is said to be **diffuse porous**.

Heart Wood and Sap Wood

- In perennial woody trees, the central portion of stem is darker in colour. Further it is hard and tough due to deposition of resins, tanins, gums and formation of tyloses. This central **hard, tough** and **darker** region constitutes **heart wood** or **duramen**. The conduction function of heart wood stops due to formation of tyloses in vessels and hence heart wood is **mechanical in function**. The heart wood is generally used for **making furniture**.
- The outer or peripheral portion of the trunk is **lighter in colour** and **soft** which performs the function of **conduction of water** and **minerals** and it is known as **sap wood** or **alburnum**. This wood is used for making **pulp wood, tool-handles** etc.

Tyloses

- These are **balloon-like** structures which are produced due to ingrowth of adjacent xylem parenchyma cells into the lumen of xylem vessels **through pits**. Tyloses always passes through pit. Balloon like structures which do not pass through pits are called tylosoides e.g.; in resin canal. Tyloses are always found in **heart wood**.

B. Secondary Growth by Cork Cambium

In many woody plants further increase in girth takes place by formation of new tissue in extrastelar regions. These new tissues are called **periderm**. Periderm is made up of three tissues:

(i) **Phellogen (=cork cambium) :** It is a **secondary lateral meristem** that may arise from permanent living cells of **hypodermis** or **outer cortex**. It is composed of a **single layer of meristematic cells**. In **transverse section** the cells appear almost rectangular and **radially flattened**. Its cell divide in a tangential plane, cutting cells towards its inner as well as outer face.

(ii) **Phellem (=cork)**

- These cells are formed as a result of **tangential and periclinal divisions of phellogen cells towards the outer face**.
- These cells are compactly **arranged** and have thin **cellulose walls** in the beginning. As they mature there is a **gradual loss of living matter** and cells get elongated **radially, vertically** or **tangentially**. The cell walls become **thick** because of development of fatty substance called **suberin**. Suberin is **impervious to water**. In *Quercus suber* which yields bottle cork, the cavities of cork cells are filled with air which makes the cork light in weight. It also provides **thermal insulating qualities**.

(iii) **Phelloderm (=secondary cortex) :** Layers of thin walled cells cut off towards the **inner side** of the phellogen form **phelloderm**. The cells of this layer are **living** and possess **cellulose cell wall**. In some species these cell may contain **chloroplasts** and **starch**. This is also called **secondary cortex**.

Bark

Bark is a loose term and is used to define **all the tissues, outside vascular cambium**.

⌧ Bark = Periderm + Cortex + Pericycle + Primary and secondary phloem.

Bark has two parts :

(i) **Outer bark**

⌧ Outer bark is dead.

⌧ All the tissue lies outside the cork cambium are called **outer bark**. It is also known as **Rhytidome**.

(ii) **Inner bark**

- The region in between the cork cambium and vascular cambium is called **inner bark**. Its most part is **living**. The main region of inner bark is the **secondary phloem** or **bast**.
- Thus bark constitute of both type of tissues - **living** and **non-living** (dead). A plant will die if we remove
 the complete bark of the plant because maximum loss
 of water occurs from this. If a ring of bark removed from the base of the plant, within a few days plant will die because phloem is separated due to this activity and plant comes in the state of deficiency of food.

Kinds of Bark

(a) **Ring bark**

- Ring bark is formed around the stem in a complete ring. When the ring of cork cambium is completed then it is known as **ring bark**.
 Example : *Betula vulgaris* - Bhojpatra, A complete distinct bark is formed in this plant. Its bark used for writing material as a paper in the ancient period.

(b) **Scaly bark**

- This bark is formed around the stem in the form of pieces of fragments. When the ring of cork cambium is not continuous, the scaly bark is formed.
- Highly obvious scaly bark is formed in *Psidium guajava, Azadiracha* (Neem), *Mangifera indica* (Mango) etc.

LENTICELS

- Lenticels are openings formed in the **bark** through which **exchange of gases** takes place. At each lenticel the cork cambium, instead of producing cork cells, forms **oval, spherical** or **irregular parenchymatous cells** which are **loosely arranged** with **abundant intercellular spaces** between them, This mass is known as
 the **complementary cells**.

SECONDARY GROWTH IN DICOT ROOT

- Secondary growth is essential in roots to provide strength to the growing aerial parts of the plants and fulfill the requirement of water and minerals.
- Secondary growth is **not found in monocot roots**.
- It occurs due to the activity of **vascular cambium** and **cork cambium**.

Activity of Vascular Cambium

- The **parenchymatous cells** on the inner side of the phloem become **meristematic** and gives rise to a **strip of cambium**.
- The **parenchymatous cells** lying in between xylem and phloem bundles also become **meristematic**.
- After this, the portion of the pericycle lying opposite the protoxylem becomes **meristematic** and forms a **strip of cambium**. Thus, a **wavy cambium** is formed extending over the xylem and down the phloem.
- It begins to cut off new cells on both sides but more on the inside. As a result of increased formation of new cells on the inner side the cambium and phloem are pushed outwards. The wavy cambium soon becomes **circular**.
- The whole of the cambium ring behaves in the same way as in the stem, giving rise to the **secondary xylem** on the inside and **secondary phloem** on the outside.
- The cambium forms **distinct radial bands of parenchyma** against the protoxylem.
 These are the **primary medullary rays**.
- Some medullary rays are also formed by the cambium along the inner edge of the phloem and are called **secondary medullary rays**.
- The amount of secondary phloem is much less than the secondary xylem.
- The primary phloem gets crushed.

Activity of Cork Cambium

- The cork cambium may develop either from the **pericycle** or the **phloem.**
- The cork cambium produces a few **brownish layers of cork** (phellem) on the **outside** and the **secondary cortex** (phelloderm) on the inside.
- The bark forms only a thin covering. Here and there few lenticels may be developed.
- The cortex and endodermis become compressed and soon slough off.

Healing of wounds

- Wounds in plants are formed due to **external injuries**. Healing of wounds is important for plant protection otherwise bacteria, fungi or other microbes may cause diseases. Besides this additional evaporation from the wound area may cause damage to the plants. If the wound is **superficial**, the exposed cells **die** and **dry up**. In case of **deep wounds**, the uninjured living cells below the wound become meristematic and produce a mass of undifferentiated parenchyma cells. This is known as **callus**.
- A cork cambium develops in peripheral layers of the callus, which forms the **wound cork**. The **wound cork** heals up the wound.
- Sometimes, the callus overgrows the wound and forms characteristic **knot** on the stem. Generally **knots** are formed when the cut base of branches get burried in main axis and get completely closed inside it due to secondary xylem. These closed structures are called **knots**.

Anomalous Secondary Growth in Stem

(i) **Sequential or successive ring of vascular cambium :** In some of the plants, a new ring of vascular cambium is formed in each year. This is formed out side the previous ring.
Examples : *Cycas, Gnetum, Mirabilis, Boerhaavia, Bougainvilia* etc.

(ii) **External Stelar vascular cambium :** Vascular cambium is formed from the pericycle in plants of **Amaranthaceae** and **Chenopodiaceae** family. A complete ring of vascular cambium is formed from the pericycle.

(iii) **Interxylary Cork :** Perenchyma of secondary xylem becomes meristematic in some of the plants and behave like a cork cambium. It means cork is formed to the interior of wood.
Example : *Artemesia*

(iv) **Cork cambium from Epidermis :** Cork cambium originates from the epidermis in same of the plants.
Examples : *Solanum dulcamara, Quercus suber* (oak). Commercial cork is obtained from the oak.

(v) **Formation of cork cambium from pericycle :** Cork is derived from the pericycle in some plants.
Examples : *Thuja, Clematis*

Secondary Growth in Monocotyledons

- In some members of plants such as *Dracaena, Yucca, Agave, Aloe arboresence, Lomandra, Kingia, Senseviera.* Vascular cambium formed from the outer region of the ground tissues. Parenchyma is formed towards the outside by the vascular cambium and vascular bundles are formed toward the inner side.
- In some plants, the girth of the stem increased without cambium. Such as - *Palms, Musa, Tulipa* etc.
- The apical meristem of these plants is special type. This is known as **primary thickening meristem.**
- This apical meristem is responsible for the growth in both length and girth (thickness) of the plant.