Tissue Systems and Anatomy of Organs

Objectives

After going through this lesson, the learners will be able to understand the following:

- The Tissue Systems
  - The Dermal System
  - The Ground Tissue System
  - The Vascular Tissue System
- Anatomy of Plant Organs
  - General Anatomy of Root
  - General Anatomy of Stem
  - General Anatomy of Leaf

Content Outline

- The Tissue Systems
- The Dermal System
- The Ground Tissue System
- The Vascular Tissue System
- Anatomy of Plant Organs
- General Anatomy of Root
- General Anatomy of Stem
- General Anatomy of Leaf
- Summary

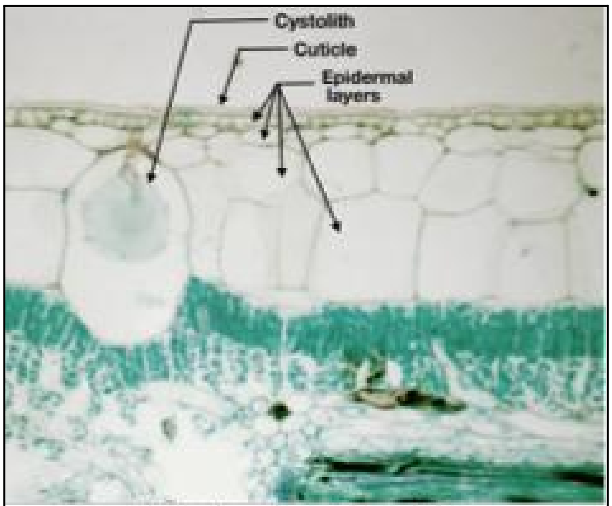
The Tissue Systems

The permanent tissues in different organs of plants are organised into **tissue systems** which perform certain distinct functions. The tissue systems are comprised of cell types that are functionally related. Most organs of the vascular plants com-monly possess three basic types of tissue systems, the **dermal** (often referred to as the **epidermal) tissue system**, the **ground tissue system** and the **vascular tissue system**. The primary structural differences in various plant parts, especially, root, stem and leaf, lie in the relative distribution of ground and vascular tissues.

The Dermal System

The dermal tissue system is composed of the outer cell layer/s which covers the plant. Its primary function is to protect the inner tissues. In plants with only pri-mary growth, the epidermis forms the dermal system but where secondary growth has occurred through activity of cork cambium, the epidermis is destroyed and is replaced by periderm. The periderm, including cork and the secondary cortex, acts as a protective tissue and is considered as part of the dermal system. Periderm will be considered in the module dealing with secondary growth.

In a broad sense, **epidermis** is the outer layer of cells that covers all parts of the primary plant body, viz. roots, stem, leaves, flowers, fruits and seeds. However, often the epidermis of root is called **epiblema** or **rhizodermis** and is considered as being distinct from epidermis of shoot as the two differ in their origin, structure and function.



Vertical section of *Ficus* leaf

Fig. 1

- Epidermis is usually single–layered. Rarely, in some plants, epidermal cells undergo periclinal divisions resulting in multi-layered epidermis (fig. 1). Cells of subsurface layers appear different from those of outer layers as well as the underlying ground tissue. These cells lack chloroplasts and commonly store water (e.g., in the leaves of xerophytic plants such as *Nerium, Ficus,* and in the aerial roots of epiphytic orchids).

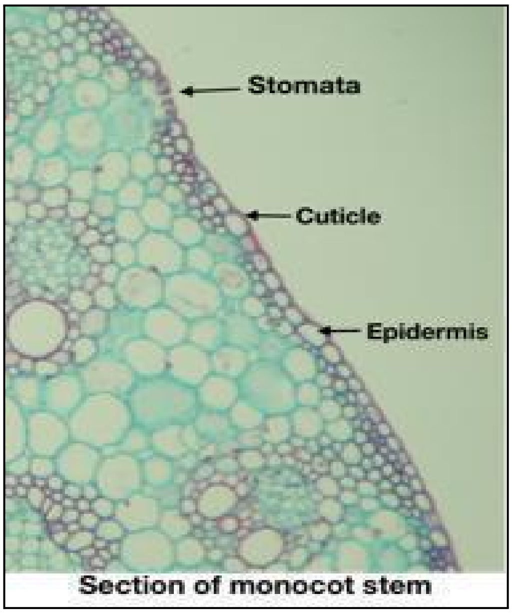


Fig. 2

- Epidermis is a complex tissue made up of a variety of cells with different functions. However, the majority of cells are living, uni-nucleated and highly vacuolated parenchymatous cells (fig. 1).
- Epidermal cells are elongated or isodiametric in shape and are closely packed without intercellular spaces (figs. 2-4). The cells appear barrel-shaped in sections because of the convexly curved outer and inner periclinal walls of the cells (fig. 2).
- Cells possess cellulosic walls. The outer surface of the walls exposed to air are covered by a protective layer called the cuticle (fig. 2). The cuticle is composed of lipid components, cutin and cutan forming the matrix, and wax which may be present within the matrix or deposited over the matrix as epicuticular wax.

  The thickness of the cuticle depends on the species and the environmental conditions; thicker cuticles are generally found in xerophytes.

  Cuticle is the first protective barrier to pathogens as well as to movement of water, restricting water loss through the exposed parts of the plant. Cuticle is quite resistant to oxidation and attack by microbes and, therefore, is found well preserved in fossils.
- In some plants, the epidermal cell walls may become lignified and the cells may appear to be sclerenchymatous such as in the epidermis of hard seed coats (e.g., legumes), and old stems (e.g., maize).
- Epidermal cells contain a thin layer of cytoplasm surrounding a large central vacuole. Except the guard cells of stomata, all the other cells lack chloroplasts (fig. 3-5).

However, epidermal cells of many submerged aquatic plants and some shade plants are found to possess chloroplasts. Epidermal cells may store starch grains, protein bodies, crystals (e.g. cys-tolith), mucilage, silica bodies, phenolic compounds such as tannins and pigments such as anthocyanin (fig. 3).

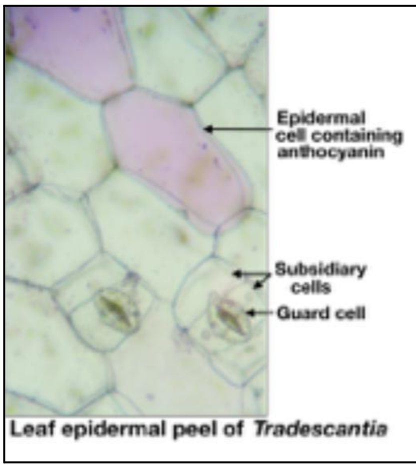


Fig. 3

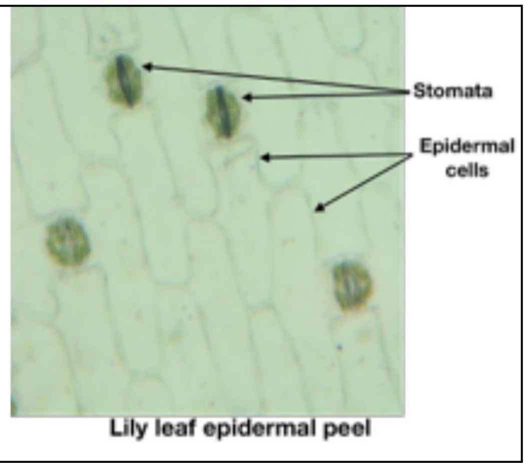


Fig. 4

- Stomata are special structures found in the epidermis of aerial parts of almost all plants; saprophytes and total parasites are the exceptions. They allow exchange of gases during photosynthesis and occur most abundantly on the leaves. Root epidermis lacks stomata.

Stomata (singular stoma) are pores or openings in epidermis, each bounded by two specialised epidermal cells, the guard cells, which regulate the –

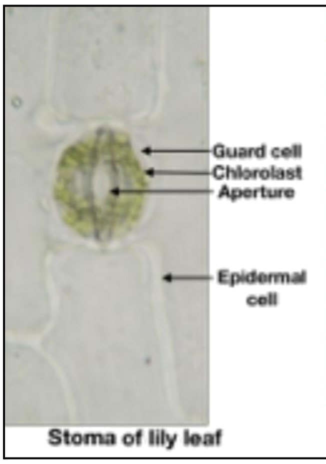


Fig. 5

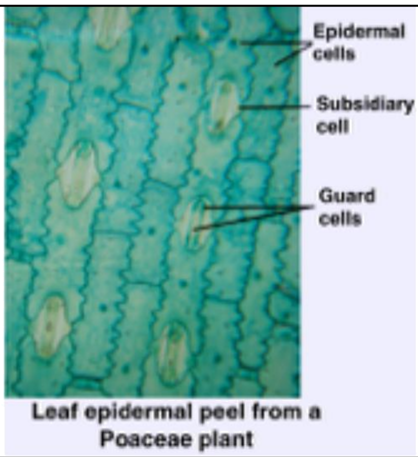


Fig. 6

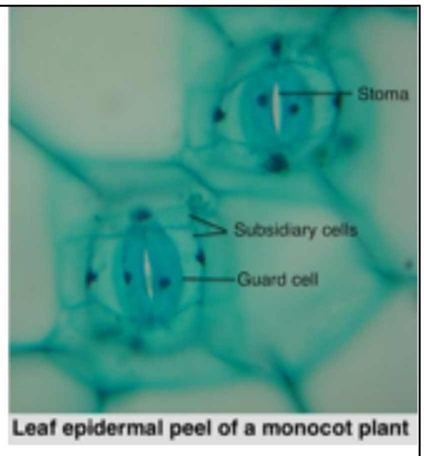


Fig. 7

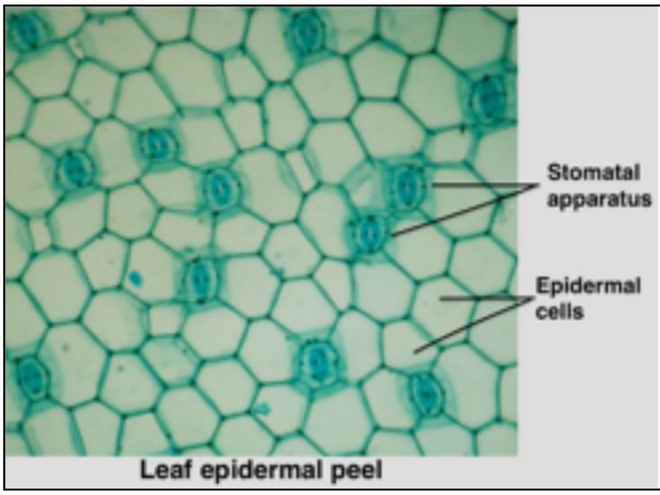


Fig. 8

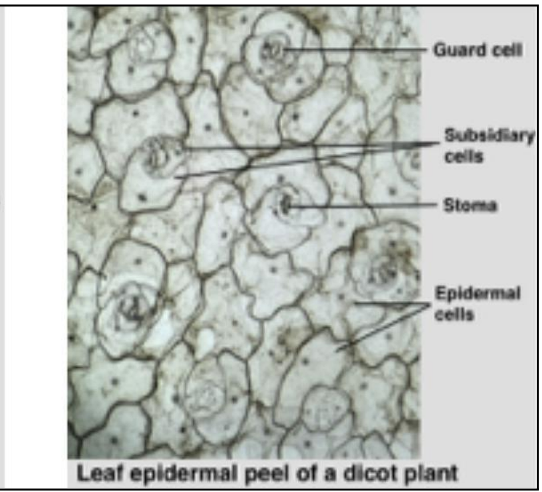


Fig. 9

opening and closing of the pore. In the majority of dicot and monocot families the guard cells are kidney-shaped (fig. 3-5, 7); they are dumbbell-shaped in species of some monocot families such as Poaceae, Cyperaceae, Arecaeae (fig. 6). The guard cells contain chloroplasts (fig. 4, 5) which are, however, photosynthetically non-functional.

In many plants the guard cells are surrounded by special epidermal cells that are different from other epidermal cells in shape and size and are called the **subsidiary cells**. The guard cells along with the subsidiary cells constitute the **stomatal apparatus** (fig. 6-9)**.**

The pore is opened when the guard cells become turgid (swell by flow of water into the cells) and closed when they become flaccid (shrink by the exit of water out of the cells). The kidney-shaped guard cells have a thick inner wall bordering the pore and a thin outer wall that is in contact with the other epidermal cells. The cellulose microfibrils of the walls radiate from the inner wall to the outer wall and this arrangement restricts width-wise swelling of the guard cells. The ends of the guard cells are attached to one another and are held firmly in place by surrounding epidermal cells. When the guard cells become turgid, they can swell only lengthwise. Since the cells are attached at the ends, they adjust the increase in length by curving away from one another and open the pore. In the dumbbell-shaped guard cells, the walls in the narrow central part of the cells are unevenly thick-ened while the swollen ends have thin walls. When the cells become turgid, it is the ends which swell and separate the straight central parts of the cells from each other creating an opening.

Stomata open during day and close at night except in plants showing Crassu-laceaean acid metabolism (CAM plants) where stomata open at night and close during the day.

- **Trichomes** or **hairs** are outgrowths of epidermis and, rarely, of subepidermal cells found on all parts of the plant body such as root, stem, leaf, flower, fruit, seed. They exhibit enormous variation in structure and function. Single-celled **root hairs** arise from the epiblema of roots and are involved in absorption of water and minerals from the soil. The trichomes or hairs of the shoot are of many different types structurally. They may be single-celled (fig. 10), multicellular uniseriate or multiseriate, branched dendritic (fig. 11), simple unbranched (fig. 12), stellate, peltate or scale-like, glandular (fig. 13), papillate or vesiculate (fig. 14). Structurally uniform types of trichomes have been found in some families, genera and species, and therefore, have often been used in identification and classification of taxa.

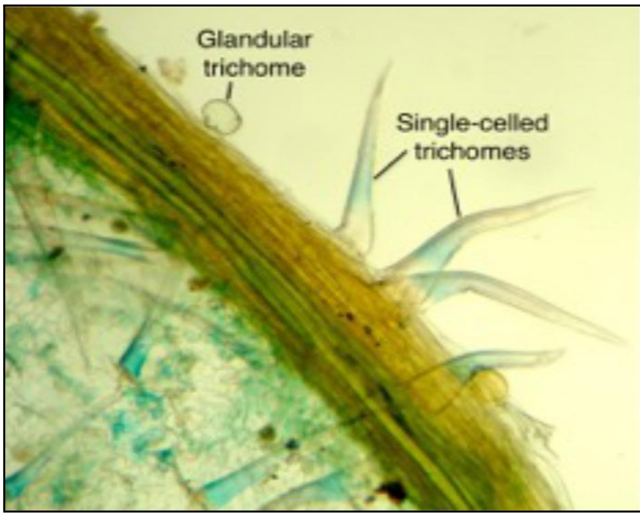


Fig. 10

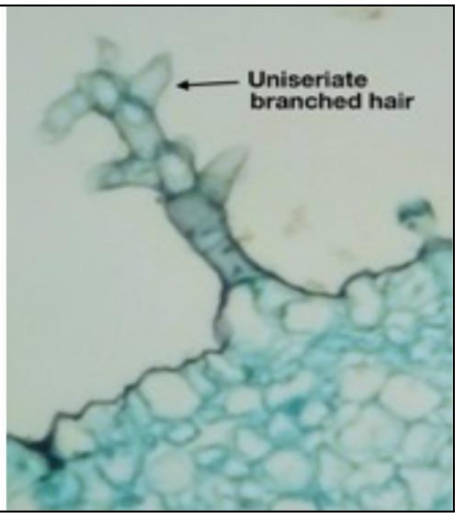


Fig. 11

The trichome cells generally possess cellulosic walls covered by cuticle. The cells may be highly vacuolate or densely cytoplasmic as in glandular hairs. Some hairs may be green and contain chloroplasts while others may contain pigments such as anthocyanins (e.g. hair of *Tradescantia*) and crystals (e.g.*Cannabis*). The glandular or secretory trichomes may contain alkaloids (e.g. *Cannabis*), toxins (e.g. *Urtica*), mucilage (e.g. *Pinguicula*) , essential oils (e.g. *Ocimum*), nectar (e.g. *Abutilon*), digestive enzymes (e.g. *Drosera*), and salts (e.g. *Chenopodium*) etc.

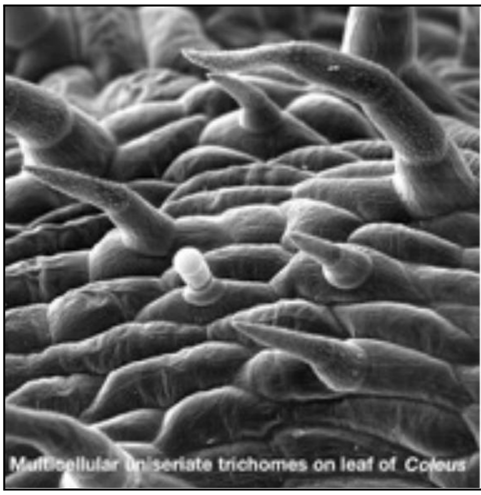


Fig. 12 **Fig. 13**

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Fig. 14 **Fig. 15**

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Trichomes perform a variety of functions. They reduce water loss through transpiration. Root hairs and foliar hairs of epiphytes absorb water and minerals. Polyphenol containing trichomes protect against ultraviolet radia-tion damage. Mucilage and digestive enzyme secreting hairs of carnivorous plants help to trap and digest animal prey. The alkaloid, toxin, essential oil secreting trichomes protect plants from plant eating pests and herbivores. Salt secreting hairs remove excess salt and prevent accumulation of toxic concentrations of salt in the plant. Nectar secreting hair attract polli-nators. Hairs on seed surface help in dispersal (e.g., cotton, fig.14).

The Ground Tissue System

The ground tissue system, also called **the fundamental tissue system, includes** all the tissues except the dermal and the vascular tissues, i.e., it includes tissues which fill up the spaces between the dermal and vascular tissues in the plant.

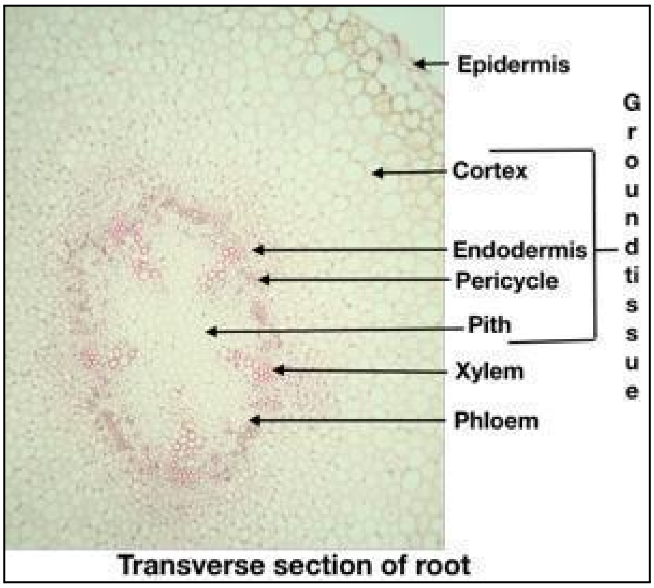


Fig. 16

It consists of simple tissues such as parenchyma, collenchyma and sclerenchyma making up the cortex, endodermis, pericycle, primary medullary rays and pith of roots (fig. 16) and stems, the mesophyll of leaves, and the pulp (excluding the vas-cular tissue) of fruits. Cells of the ground tissue may synthesise and secrete or store latex, gums, resins, alkaloids, pigments, essential oils, tannins and mineral crystals, etc.

The Vascular Tissue System

The vascular tissue system **consists of two types of complex conducting tissues, the xylem and the phloem tissues**. **Vascular bundles in the stem and leaves of di-cotyledonous plants contain, in addition to xylem and phloem, vascular cambium tissue which can**

give rise to secondary vascular tissue. Such vascular bundles are called open vascular bundles **(fig. 21)**. Vascular bundles of roots, stem of monocots and a few herbaceous dicots which lack vascular cambium are called **closed vascu-lar bundles** (Fig. 18-20)**.**

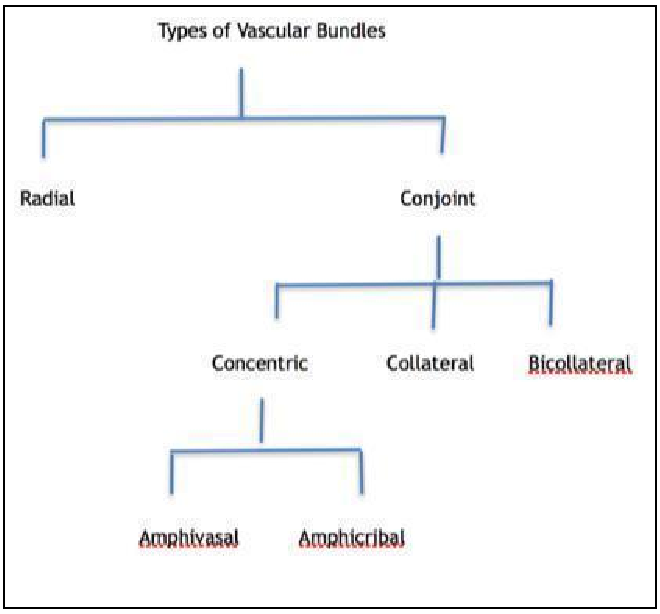
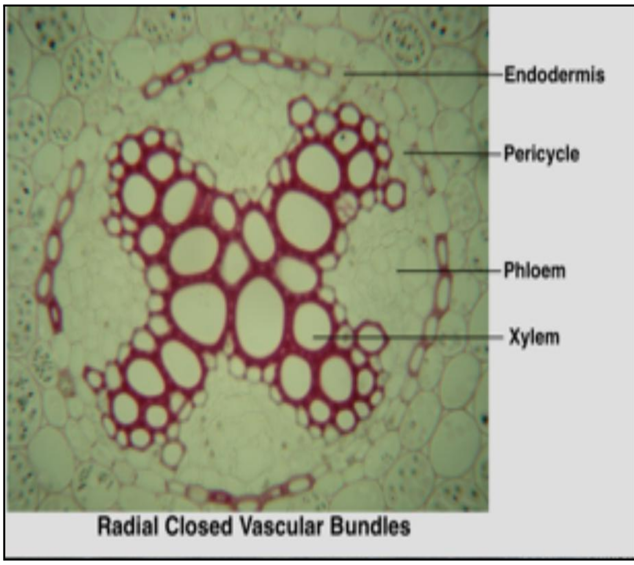


Fig. 17

Vascular bundles are categorised into two types based on the relative position of xylem and phloem tissues. **Radial vascular bundle** found in roots is characterised by xylem and phloem tissues present alternating with each other in different radii of the organ (fig. 18). In **conjoint vascular bundles,** xylem and phloem tissues are present adjacent to each other in the same radius, as in the vascular bundles of stem and leaf. Conjoint bundles may be of concentric type or collateral type. In **concentric** type of bundles, one tissue encloses the other; if xylem surrounds



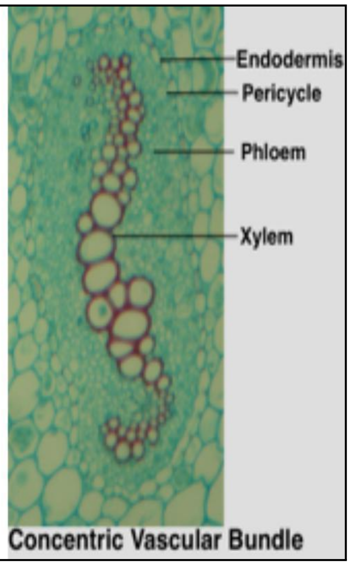
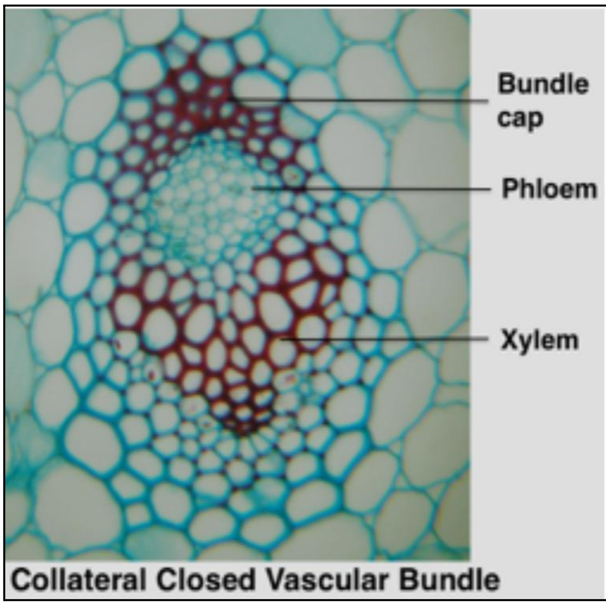


Fig. 18 **Fig. 19**

phloem is called **amphivasal (or leptocentric) vascular bundle**, if phloem encloses xylem (fig. 19), it is called **amphicribral (or hydrocentric) vascular bundle**. In **collateral vascular bundles**, phloem is either present only toward the outer side of xylem (fig. 20) or sometimes, toward both outer and inner side of xylem (**Bicollateral vascular bundles**) (fig. 21).



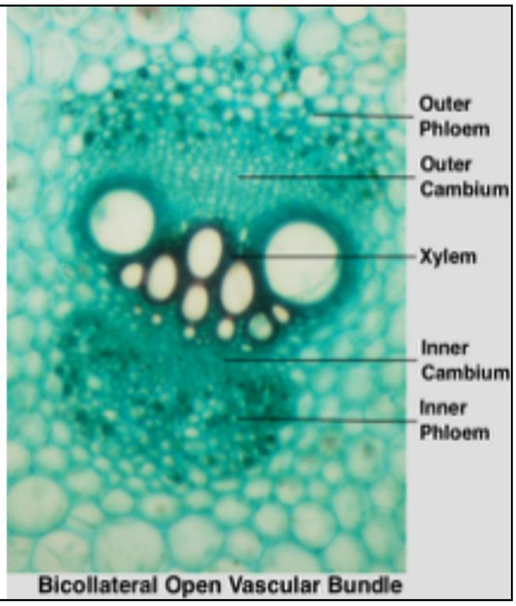


Fig. 20 **Fig. 21**

Anatomy of Plant Organs

The best method to understand the internal anatomy or structure of organs is to cut sections and study them under a microscope. Transverse sections have been useful in studying plant organs. A young root or stem shows the following tissue organ-isation from outside to centre:

Epidermis, Cortex, Endodermis, Pericycle, Vascular bundles and Pith. Vascular system together with pericycle and pith is also known as stele.
Leaf has mesophyll tissue in place of the cortex.

General Anatomy of Root

The transverse section of a young root shows the following tissue organisation: **Epidermis/Epiblema/rhizodermis**: It is the outermost single layer of cells covering the root. Many of the cells elongate as root hairs. The epidermal cells are highly vacuolated and uninucleate (fig. 22, 23). They possess cellulosic walls covered by a thin cuticle layer.

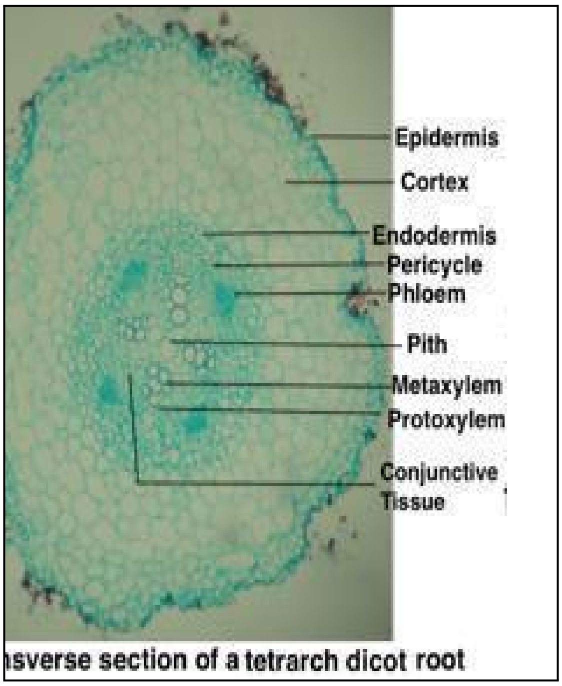
Cortex: Inner to epidermis is a thick cortex consisting of many layers of loosely packed parenchyma cells containing intercellular spaces (fig. 22, 23). The cells are uninucleate and vacuolated with thin cellulosic walls.

Endodermis: It is considered as the innermost layer of cortex and is comprised of elongated barrel-shaped cells. The radial walls of the cells have depositions of suberin, a water impermeable waxy substance, as bands or strips known as **Caspar-ian strips,** named after the scientist, Robert Caspary, who discovered them. In older roots, especially of monocots, the entire radial and inner tangential walls of cells become impregnated with a thick deposition of suberin and lignin.

A few cells, usually near the xylem arms lack suberin deposition and are called the passage cells.

Water and minerals are pumped into the stele through the passage cells of endo-dermis. The endodermal cells with suberized walls act as barrier and prevent them from leaking back into the cortex. The suberin blocks the passive flow of water and dissolved minerals through the walls (apoplastic pathway) and forces their flow through the cell protoplast (symplastic pathway), thus preventing their passive dif-fusion across walls.

Pericycle: It comprises of, generally, one to few layers of small parenchyma cells which have retained the ability to divide. Secondary or lateral roots, both in monocotyledons and dicotyledons, are formed as a result of the meristematic ac-tivity of these cells. Some of the pericycle cells in dicotyledon roots form part of vascular cambium which gives rise to secondary vascular tissue.



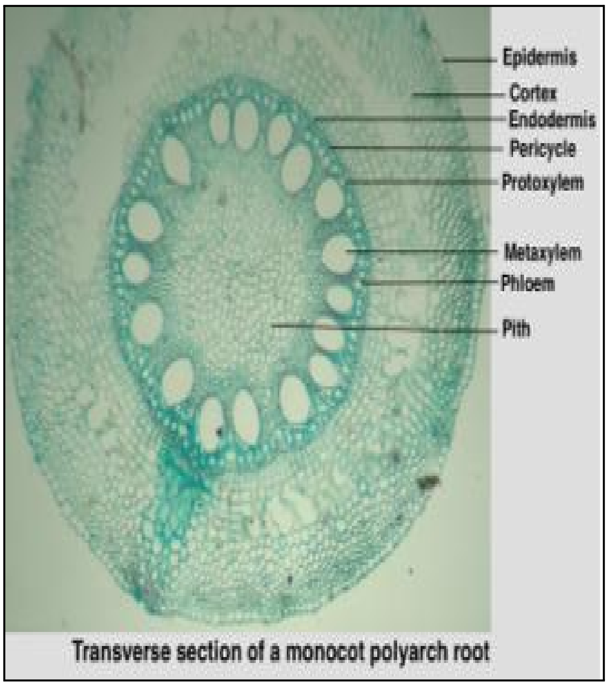


Fig. 22 **Fig. 23**

Vascular Tissue: It is present as a central cylinder inner to the pericycle. It is closed and radial with xylem and phloem tissues present separately next to each other in different radii (figs. 18, 22, 23). The parenchyma tissue between the xylem and phloem tissues is called the **conjunctive tissue**. In older dicotyledon roots, cells of conjunctive tissue become meristematic and form vascular cambium which gives rise to secondary vascular tissue. Xylem is exarch, i.e., its development is centripetal with the early formed protoxylem present toward the outside and the metaxylem elements developing inward. Roots may also be referred to by the number of protoxylem arms or poles present between the phloem strands. Root with one, two, three, four or more arms are called, respectively, monarch, diarch, triarch, tetrarch, and so on. Generally, roots of dicots are diarch to hexarch while those of monocots have more arms and are called polyarch.

Pith: The central part of the root with parenchymatous cells constitutes the pith figs. 22, 23). In many dicot roots, pith is absent as the centre is occupied by xylem (fig. 18).

The root anatomy of dicotyledons and monocotyledons is similar except for a few differences.

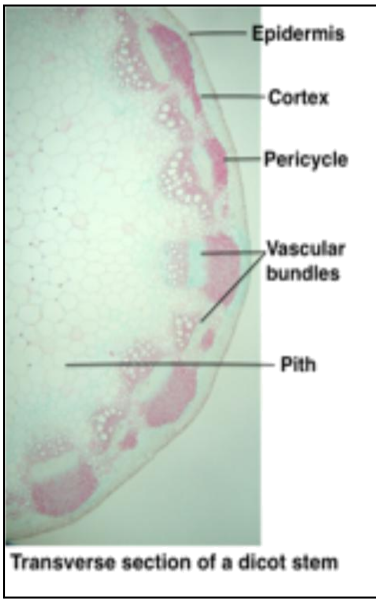
Character	Dicotyledonous root	Monocotyledonous root
Number of vascular bundles	2-6 (diarch-hexarch)	More than 6 (polyarch)
Pith	Small or absent	Large
Vascular cambium	Develops	Does not develop

General Anatomy of Stem

Transverse section of a young stem shows the following structure:

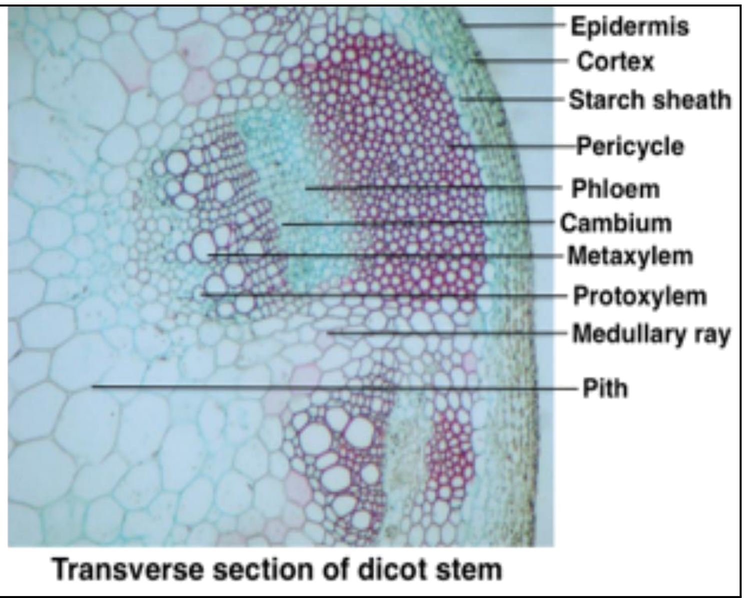
Epidermis: It consists of, usually, a single layer of epidermal cells. It may bear various types of, mostly multicellular, trichomes. Stomata are also found, especially, in green stems.

Cortex: It is a thin region present inner to the epidermis (fig. 24). In general, the cortex in the stem is heterogeneous with different types of tissues (fig. 25). **Hypodermis**, which is located just below the epidermis, consists of a few layers of collenchyma or sclerenchyma cells which provide support and protection to the stem. However, below the stomata chlorenchyma cells are found. Inner to the hypodermis, is a few-layered **general cortex** made up of thin-walled parenchyma cells with intercellular spaces. In green stems, cortical cells contain chloroplasts. In some plants, laticifers and secretory canals/cavities are found in the stem cortex. Cortical cells may also store substances such as starch, proteins, lipids, tannins, alkaloids, phenols, etc.



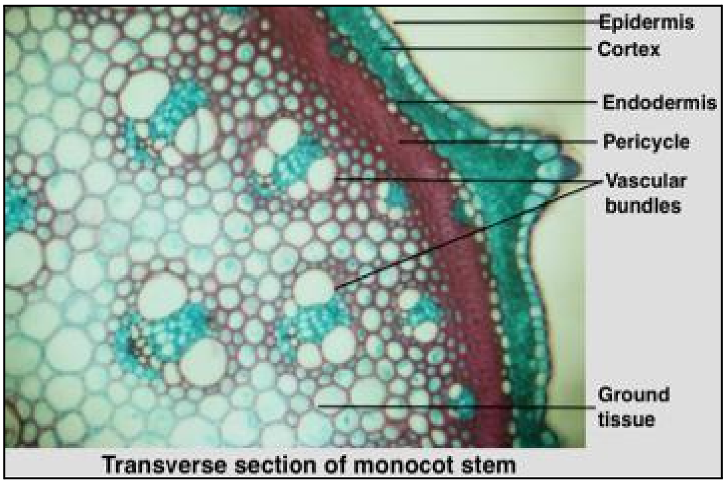
Transverse section of a dicot stem

Fig. 24



Transverse section of dicot stem

Fig. 25

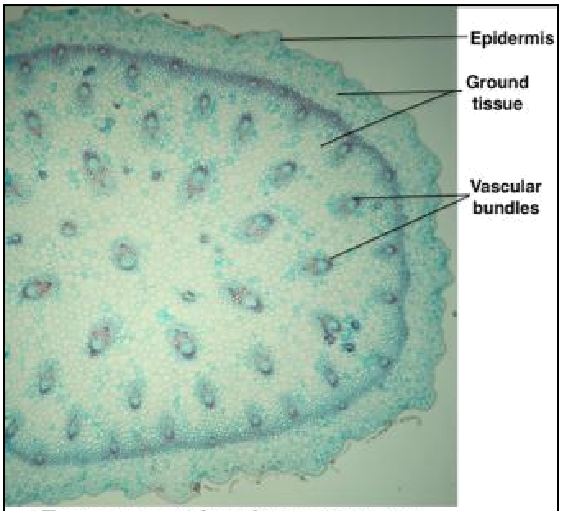


Transverse section of monocot stem

Fig. 26

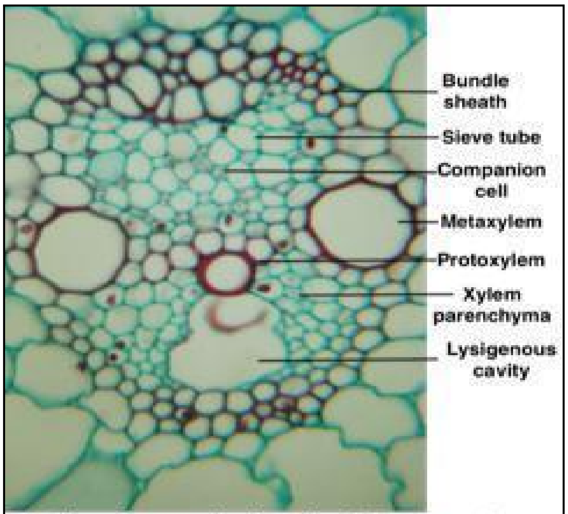
Endodermis: Considered as the innermost layer of cortex, endodermis consists of somewhat barrel-shaped cells (fig. 25, 26). In stems, endodermis is not a very distinct layer. Often the layer is recognised by the presence of starch in the cells and is called the starch sheath. In some monocotyledons, e.g Poaceae, endodermis is absent.

Pericycle: It is a tissue found inner to the cortex. It may be present as a many-layered continuous cylinder (fig. 26) or in bundles (bundle caps) adjacent to vascular bundles on the outside (fig. 25). Generally, the pericycle of the stem consists of sclerenchyma tissue. Like endodermis, pericycle is also not found in the stem of some monocotyledons.



Transverse section of a monocot stem

Fig. 27



Section of a vascular bundle of Poaceae stem

Fig. 28

Vascular System: It consists of conjoint, mostly collateral or bicollateral, vascular bundles organised in three basic types in internodes of stem. In the first type, vas-cular bundles are present close to each other separated by very narrow medullary rays, and appear to form a more or less continuous cylinder. In the second type, discrete vascular bundles separated by wide primary medullary or pith rays, are present in ring/s (fig. 24). In the third type, vascular bundles are scattered in the ground tissue (e.g. most monocots and some herbaceous dicots) (fig. 26, 27).

In most dicots, vascular bundles are open with one to a few layers of vascular cambium present between xylem and phloem, whereas, in monocots and some-herbaceous dicots (e.g. *Ranunculus*) they are closed or lack vascular cambium. No secondary growth takes place in stems with closed vascular bundles. Such closed-vascular bundles are usually surrounded by a sheath of sclerenchyma cells (fig. 28). Xylem is endarch or centrifugal; the first formed xylem elements (protoxylem) are located inward toward the pith while the later formed (metaxylem) elements develop toward outside i.e., toward phloem tissue (fig. 25, 28).

Pith: It consists of thin-walled parenchymatous cells and is located in the centre of the stem (fig. 24). It is absent or not differentiated in some monocots (e.g., Poaceae) (fig. 26, 27).

There are a number of differences in the structure of the stem of a dicot and a monocot.

Character	Dicotyledonous stem	Monocotyledonous stem
Differentiation of ground tissue into cortex, endodermis, pericycle and pith	Differentiated	Mostly not differentiated
Vascular bundles	Generally open, not enclosed in sclerenchymatous sheath and arranged in ring/s	Closed, surrounded by sclerenchymatous sheath and generally scattered
Phloem parenchyma	Present	Absent

General Anatomy of Leaf

Leaves in general are flattened structures and, therefore, have an upper, adaxial or ventral surface and a lower, abaxial or dorsal surface.

The vertical section of a photosynthetic leaf shows the following tissues:

Epidermis: It is generally single layered and covers both the surfaces of the leaf. Mul-tilayered epidermis is found in leaves of xerophytes (e.g., *Nerium, Ficus*). Stomata occur on only one surface (e.g. on the upper surface of floating leaves of hydrophytes and lower surfaces of leaves of most xerophytes) (fig. 29), on both the surfaces with equal frequency (e.g., *Bryophyllum*, *Zea mays*) (fig. 30, 31) or with more abundance on lower surface (e.g., most mesophytes). Trichomes are often found on leaf epidermis. In some monocot plants, large epidermal cells, the bulli-form cells fig. 31), are present which cause rolling and unrolling of leaves. When the cells are turgid, they keep the leaf expanded but under water stress condi-tions, the cells become flaccid and make the leaf curl or roll reducing water loss through transpiration from leaf surface.

Mesophyll: The photosynthetic cells of the leaf constitute the mesophyll tissue. It is the ground tissue present between the upper and lower epidermis of the leaves and consists of chlorenchyma cells with large intercellular spaces.The mesophyll cells may be more or less similar in shape and size as in leaves of most monocots (fig. 31), or may be differentiated into two types of cells, the **palisade parenchyma** and the **spongy parenchyma** as in most dicot leaves (fig. 29, 30). The cells of palisade parenchyma are elongated columnar cells with cells that are more rounded.

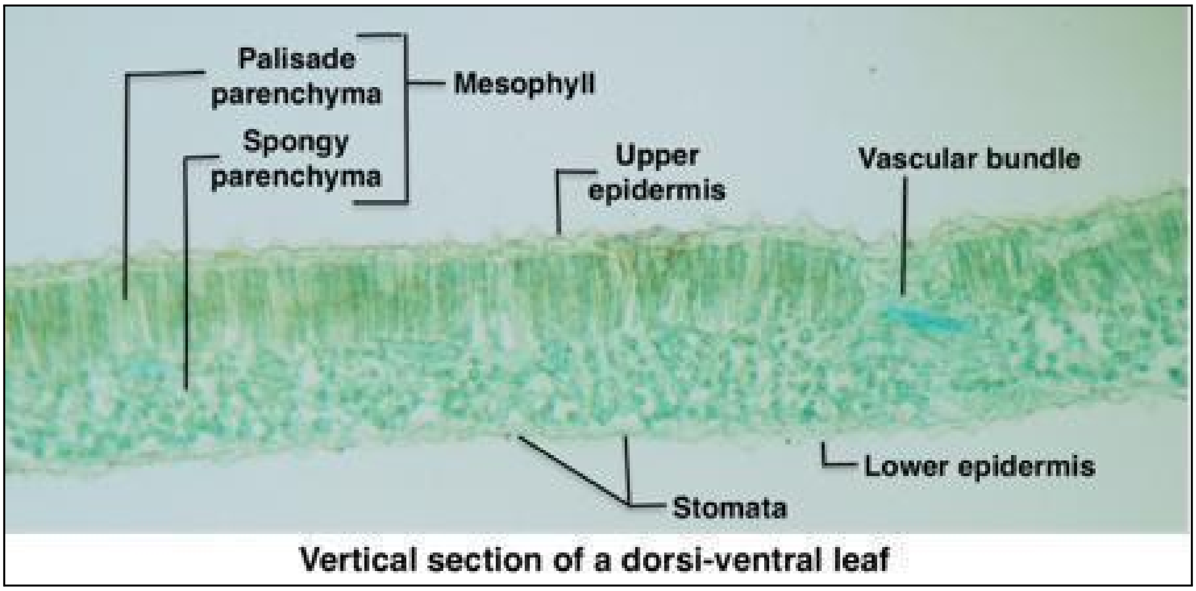


Fig. 29

The palisade parenchyma is usually found inner to the upper epidermis while the spongy parenchyma is on the lower side, inner to the lower epidermis (e.g. *Hibiscus*). In some plants, spongy parenchyma is located in the centre sand-wiched between palisade parenchyma which occurs inner to both the epidermis (e.g., E*ucalyptus, Kalanchoe*).

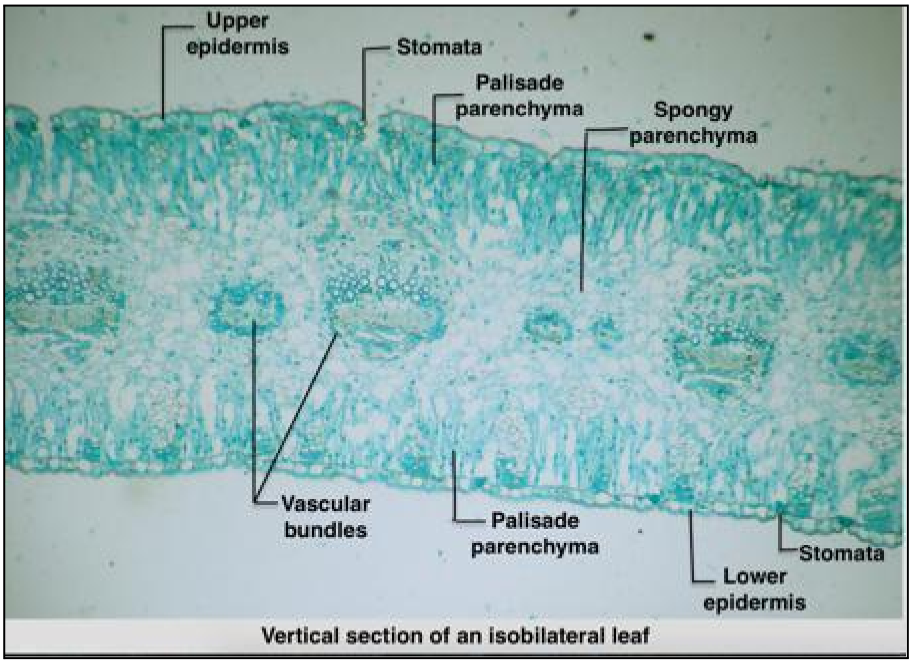
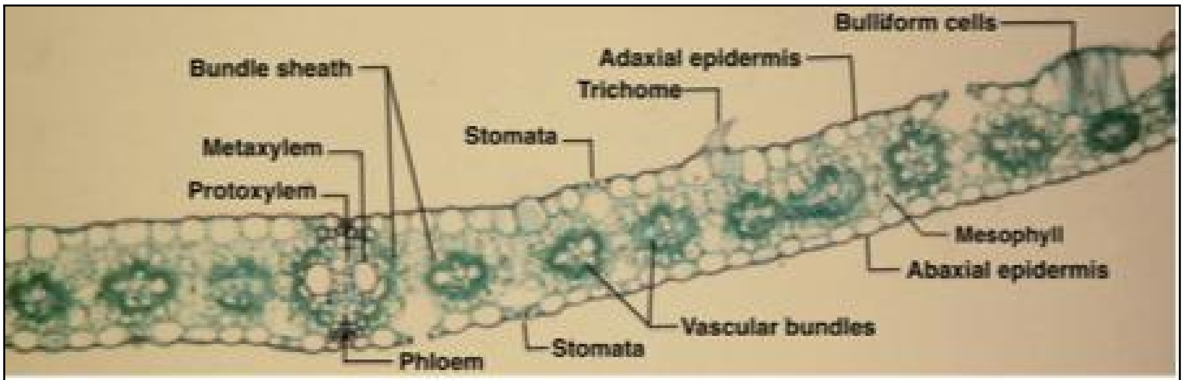


Fig. 30



Vertical section of an isobilateral leaf of Poaceae plant showing Kranz anatomy

Fig. 31

Plants which undertake the C4 pathway of photosynthesis generally possess leaves with Kranz (German word for wreath) anatomy. In the leaves of these plants large mesophyll cells with starch-containing chloroplasts surround vascular bundles like a wreath (Kranz) forming a chlorenchyma tous bundle sheath (fig. 31). The normal mesophyll cells with smaller chloroplasts surround the bundle sheath cells. The two types of cells are connected by plasmodesmata and act together to carry out C4 photosynthesis.

Vascular system: It is represented by numerous vascular bundles present in the veins and midrib, and is continuous with the vascular system of the stem. The vascular bundles are distributed throughout the mesophyll. The size of the vascular bundle depends on the size of the vein in which it is present. In the large veins or major veins, vascular bundles are surrounded by parenchyma cells lacking chloroplasts but often a few hypodermal layers inner to upper and lower epidermis, may consist of collenchyma or sclerenchyma cells which provide mechanical support to the leaf lamina. Vascular bundle in the smaller vein or minor vein is enclosed in a bundle **sheath** composed of one or two layers of compactly arranged cells. These bundle sheath cells possess suberin depositions in their walls similar to the Casparian strips in endodermal cells of root. These cells function like the endodermis of roots and control the movement of water and photosynthates to and from the vascular bundles. The sclerenchymatous bundle sheaths of many veins may extend and connect with the epidermis. These extensions are called bundle sheath extensions and provide additional mechanical strength to the leaf.

The veins in the leaves of dicotyledons form a reticulate pattern with the smaller veins branching from larger ones. In contrast, most monocot leaves have veins which are placed parallel to each other which are interconnected laterally by small bundles, especially in the wider leaves. Therefore, in a transverse section of a dicot leaf, veins are sectioned in all, longitudinal, transverse or oblique, planes (fig. 29) whereas that of a monocot leaf has veins sectioned in transverse plane with small interconnecting horizontal bundles (fig. 31).

In the vascular bundles of leaves, the xylem tissue is usually situated toward the upper or adaxial surface while phloem is present toward the lower abaxial surface (figs. 30, 31). The smaller veins contain one vascular bundle but the larger ones and midrib may contain one to many vascular bundles distributed in a circle, semicircle or irregularly.

Leaves of angiosperms may be divided into two types based on their structure; **Dorsiventral leaves** are those which have structurally different dorsal (abaxial or lower) and ventral (adaxial or upper) regions. In these leaves, palisade parenchyma is situated toward the adaxial region inner to the upper epidermis while the spongy parenchyma is present toward the abaxial region between the palisade parenchyma and the lower epidermis (fig. 29). Stomata are usually absent or very few in the upper adaxial epidermis. These leaves are found, generally, in dicots. In **isobilateral leaves,** there is no structural difference between the dorsal and ventral regions, as in most monocots. The mesophyll tissue is either not differentiated into spongy and palisade parenchyma and instead consists of simple chlorenchyma cells as in leaves of Poaceae (fig. 31), or if differentiated, then the palisade parenchyma is present on both the adaxial and abaxial regions inner to the epidermal layers (fig. 30). Stomata are found on both, upper and lower, epidermis.

Summary

- The permanent tissues are organised into tissue systems in plant organs. Tissue systems consist of cell types that are functionally related. There are three basic types of tissue systems. The dermal or epidermal system includes the outer cell layer/s such as the epidermis and periderm which cover the plant and provide protection to the inner tissues. The ground or fundamental system comprises all the tissues except those that make up the dermal and vascular systems. It is mainly involved in synthesis and storage of substances. The vascular system is made of xylem and phloem tissues and is concerned with transport of water, minerals, nutrients and other materials in the plant.

- Roots contain an outermost epidermal layer with root hairs, a wide cortex, well differentiated endodermis, parenchymatous pericycle, and vascular bundles of the radial and closed type. Xylem is exarch.
- Stems possess epidermis, generally, a thin cortex, endodermis which is not well differentiated, sclerenchymatous pericycle, and collateral vascular bundles. Xylem is endarch.
- The leaf is covered by epidermis, usually containing stomata. Trichomes are often found. Mesophyll forms the ground tissue consisting of chlorenchymatous cells and may be distinguished into palisade or spongy parenchyma tissue. Vascular bundles show a structure similar to those of stem with which they are continuous.