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Lesson: General Anatomy of Leaf

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Introduction

Leaves are one of the most important organs of the plants. They are the prime source that provide green colour to our planet earth. They capture the light or solar energy and convert it into chemical energy with the help of chlorophyll molecules that are present in chloroplast, through the process known as photosynthesis. Leaves also help plants in water absorption by the process known as transpiration because of development of strong suction pressure in the cells of leaves that in turn helps in absorption of water from the roots and root hairs. In turn, leaves also act as conservator of water in plants by modifying them into spines (*Opuntia*), phylloclade and phyllode. The leaves modified into spines not only to prevent water loss but also act as a protective agent against herbivory.

Figure: Leaves and their modifications: *Opuntia* A); *Homalocladium platycladum* – a phylloclade B); *Acacia melanoxylon* - phyllode C); *Aloe* and *Bryophyllum* - succulent plants (D-E); *Macfadenya unguis-cati* with climbing hooks F); *Lathyrus* - tendrils G); Venus fly trap - insectivorous plants H) and *Dischidia rafflesiana* - pitcher I).

A) http://en.wikipedia.org/wiki/Opuntia

B) http://commons.wikimedia.org/wiki/File:Homalocladium_platycladum_13.jpg

C) http://davesgarden.com/guides/pf/showimage/93465/

D) http://www.safeandhealthylife.com/aloe-vera-natures-precious-gift-to-life;

E) http://karnak.wikispaces.com/Herbal+Remedies

F) http://herbaria.plants.ox.ac.uk/vfh/image/index.php?item=186

G) http://www.colourbox.com/image/close-up-tendrils-of-pea-image-2151234

H) http://www.darwinproject.ac.uk/insectivorous-plants;

I) http://toptropicals.com/catalog/uid/Dischidia_rafflesiana.htm

Leaves act as a store house of minerals and food material as found in succulent plants (*Aloe* and *Bryophyllum*). Leaves act as climbing agent by forming hooks (***Macfadina unguis-cati***) and tendrils (*Lathyrus*). Leaves in carnivorous or insectivorous plants are partially or wholly modified into pitcher like structures which trap insect. In epiphytic climber, *Dischidia rafflesiana* the pitcher not only traps insects but also helps in storage of water. Leaves act as major nutrient cycler in ecosystem operating with temporal adjustment at different regions. In temperate regions, deciduous plants typically shed their leaves in autumn whereas in regions with a severe dry season, plants may shed their leaves at the end of the dry season. In both the cases, the shed leaves contribute to the nutrients of the soil. Thus, the leaf performs diverse function and proves its importance.

In contrast, many other non-seasonal plants, such as palms and conifers, retain their leaves for longer period of time; *Welwitschia mirabilis,* a monotypic genus found in Namib dessert of Namibia and Angola retains its two main leaves throughout its lifetime (approximately 1000 year or more). Many plants do not have true leaves for e.g. non-vascular plants such as mosses and liverworts. They produce flattened, leaf-like structures which are green due to presence of chlorophyll, but these organs differ morphologically from the leaves of vascular plants.

A typical foliage leaf of an angiosperm consists of a leaf base, petiole (leaf stalk), a lamina (leaf blade) and stipules (small structure located to either side of petiole base. Petiole forms a connection between leaf to stem or branches and aids in the transportation of water and sugar assimilates. These structures are not necessarily found in all plants species. The petiole or stipules are either not distinct or absent altogether, or the blade may not be laminar (flattened).

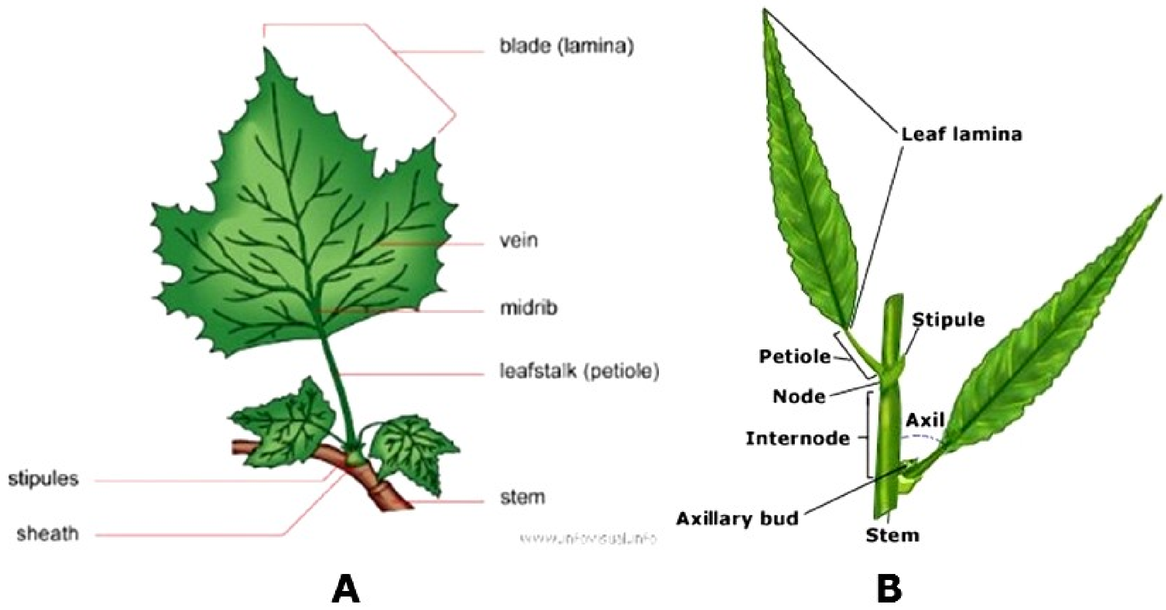

Figure: Structure of a leaf (A and B).

Source: A): http://www.1-costaricalink.com/costa_rica_trees/glossary.htm

B): http://fphoto.photoshelter.com/image/I0000OUgRcZZNVaA

On the basis of anatomical structure, two types of leaves have been recognized in angiosperms, dorsiventral (dicotyledonous) and isobilateral leaves (monocotyledonous). The dorsiventral leaves are found in dicotyledon group of angiosperms and grow in horizontal direction with distinct upper (adaxial) and lower (abaxial) surfaces. The upper surface of leaf is more illuminated than lower surface and therefore anatomical differences exist in the internal structure between the upper and lower surfaces in the leaf. The isobilateral leaves are vertically arranged on stem that makes both surfaces receive direct and equal amount of sunlight therefore they possess uniform structure on both upper and lower surfaces. Exceptionally very few dicotyledons and most of the monocotyledons have isobilateral leaves.

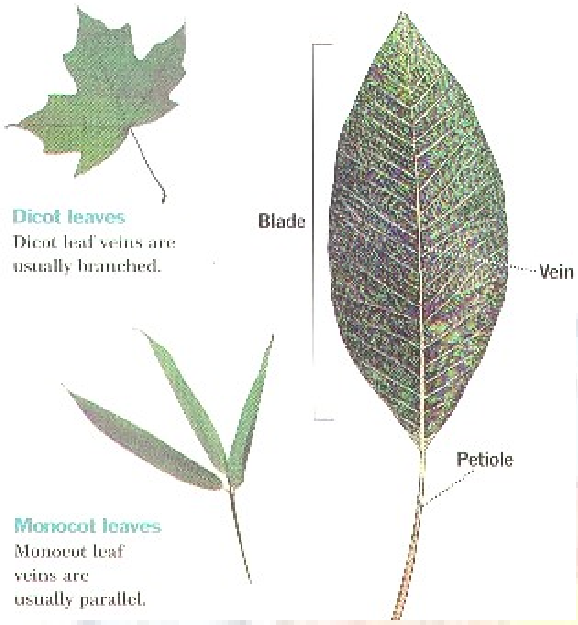

Figure: Characteristic features of a leaf.

Source: http://www.biologyjunction.com/plant_structure_bi1.htm

General anatomy of leaf

Leaves are green, flat structure with various shapes and extensively vascularized covered by a dense network of xylem which supplies water for photosynthesis and phloem, which transports the sugars produced by photosynthesis. Small hair like structures known as trichomes are present on leaf surface which have a diverse range of structure and functions in plants. Leaf is a collection of organized tissues.

The major tissue systems present are:

- Epidermis,
- Mesophyll
- Veins (vascular tissue/bundles)

Epidermis

The outermost layer of cells covering the leaf is called as epidermis. It forms the boundary separating the plant's inner cells from the external world. The epidermis serves following functions:

- Protection against water loss by the process of transpiration,
- Regulation of gaseous exchange,
- Secretion of metabolic compounds,
- Absorption of water (in hydrophytic species).

The epidermis is usually a transparent (epidermal cells generally lack chloroplasts) layer, coated with waxy cuticle on the outer side, which prevents water loss. In some species, a thin cuticle is present on the lower epidermis as well. The thick cuticle layer is mainly present in the leaves from dry climates as compared to wet climates. The epidermal cells are elongated in the leaves of monocots as compared to dicots.

The epidermis tissue system includes several differentiated cell types such as epidermal cells, epidermal hair cells (trichomes), cells of the stomatal complex such as guard cells and subsidiary cells. The epidermis continuity is interrupted with presence of pores called stomata. A stomatal complex consists of a pore surrounded on each side by chloroplast containing two guard cells, and two or more than two subsidiary cells that lack chloroplasts. Stomata regulates the exchange of gases and water vapour between the external air and interior of leaf with the help of opening and closing thereby, playing an important role in process of photosynthesis, transpiration and translocation of water and food assimilates.

Mesophyll

Mesophyll (Greek, it’s for "middle leaf") contains specialized cells that are parenchymatous in nature and may or may not contain chloroplast. They are present between the upper and lower epidermis of leaf. Due to presence of chloroplast, mesophyll cells carry out photosynthesis and are thus called as assimilatory tissue. In ferns and most flowering (dicot) plants, the mesophyll is divided into palisade and spongy parenchyma. The cells of palisade parenchyma are generally elongated, tightly packed, one, two or sometimes three layered and present below the adaxial epidermis. These cells contain more chloroplast as compared to spongy layer and the chloroplasts tend to stay close to the walls of cell to harvest maximum amount of light. Multi-layered palisade layer is seen in the leaves that are exposed to bright sunlight as compared to, leaves in shady areas or older leaves closer to the soil have single-layered palisade layer. Spongy parenchyma cells are rounded, loosely packed, present beneath the palisade layer. Loose packing of cells develops large intercellular air spaces. Fewer chloroplasts are present in spongy parenchyma cells as compared to the palisade layer. Substomatal chambers makes opening of the stomata, which are connected to the intercellular spaces present between the spongy layer cells. Many aquatic, marshy and isobilateral leaves lack these two distinct layers of the mesophyll.

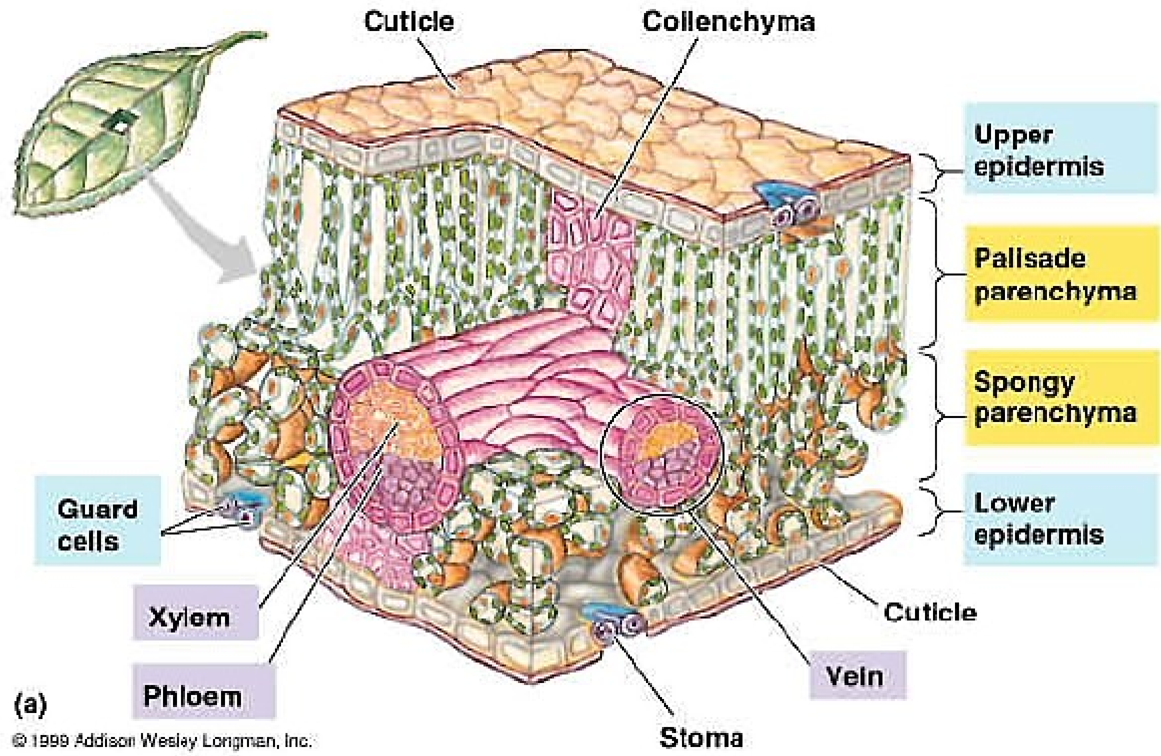

Figure: Diagrammatic representation of a leaf.

Source: http://www.biologyjunction.com/plant_structure_bi1.htm

Veins

A vein is made up of a vascular bundle and is located in the spongy layer of the mesophyll. A vascular bundle is a part of the transport system in vascular plants. The distinct pattern of the veins in leaf is called venation. At the core of each bundle are clusters of two distinct types of tissues namely xylem and phloem. Xylem helps in transportation of water and minerals from the roots to the leaf while phloem helps in transportation of sap, with dissolved sucrose to different parts of the plant for utilization and storage. The xylem lies towards the adaxial (upper) surface of the vascular bundle while the phloem lies towards the abaxial (lower) surface. Both xylem and phloem are embedded in a dense parenchymatous tissue bounded by cell layer known as bundle sheath. A vascular bundle is called collateral where the phloem and xylem lie on the same radius, with the phloem located toward the periphery of the stem and the xylem toward the center. Collateral vascular bundles may be closed or open. Closed vascular bundles lack cambium in between xylem and phloem and thus show no secondary growth. Closed collateral bundles are present in almost all monocotyledonous plants. In open collateral bundles, a layer of cambium cells is present between phloem and the xylem which shows secondary growth predominantly in the stems of dicotyledons, gymnosperms and some pteridophytic plants.

Leaf development

The development of leaf occurs from the leaf primordium which arises from shoot apex. Its development can be divided into following event or stages:

- Initiation
- Early differentiation
- Leaf axis development
- Origin of lamina
- Histogenesis of tissues of lamina
- Development of veins

Initiation

Leaf development initiates with the periclinal division in a small group of cells present in the shoot apex. The number of cell layers that begin to divide and their position on the shoot apex varies from species to species.

In Gymnosperms, two types of leaf initiation mechanism have evolved to develop the leaves from shoot apex. Evolutionary old species of gymnosperms (*Zamia*) show periclinal division in surface layer as well as in layer immediately below it (Mechanism I). But advanced species of gymnosperms (*Taxodium*) shows periclinal division in cell layer immediately below the surface layer (Mechanism II). Angiosperms have inherited both the mechanism of the leaf initiation in separate groups. All dicots and some monocots follow mechanism II, where mostly the cells present below the surface layer participate in periclinal division except in one of the monocot (Grass family members) which follow Mechanism I.

Leaf differentiation

After initiation, the leaf primordial cells undergoes continuous cell division and forms protoderm on shoot apex known as leaf buttress. The leaf buttress consists of protodermal layer, inner mass of ground meristems and a procambial strands which develops acropetally from the nearby procambium of the stem.

Development of leaf axis

Many gymnosperms and angiosperm plants posses leaf axis. It is important to note that leaf axis develop before the development of leaf lamina or leaflets. The leaf axis originates from the primordium. Rapid division of primordium leads to development of flat adaxial side cone like structure having tapering ends. Tip acts as apical meristem and continues to divide and produce new cells. This axial increase is accompanied by increase in width and thickness. The tip activity shows variation across plant kingdom that gives rise to variation in structure of leaf axis.

Origin of lamina

During development of the leaf axis, the cell of adaxial margin continues to divide much more than the cells of ground meristem. Continuous growth of adaxial margin, leads to the development of two wings like strip on either side of margin. In leaves with a petiole, the marginal growth is depressed in the basal portion of the leaf axis which gives rise of petiole. The wings margin contains a marginal/submarginal initial that by division forms young lamina.

In pinnately and palmately compound leaves, the lateral leaflet develops from the adaxial marginal meristem of the axis of the young leaf as two rows of papillae. These may be acropetel (*Caraya*) or basipetal. The development of a lobed leaf is a result of differential activity of the leaf margin which starts early in ontogenesis. In fenestrated leaf, as in *Monstera deliciosa* holes develop at an early ontogenic stage due to necrosis in small patches of tissue.

Histogenesis of tissue of lamina

The growth on the margins occurs for a longer period than at the apex but ceases early thereafter, further growth of lamina is brought about by the cell division in the various cell layers of the lamina. These cell divisions are mostly anticlinal and lead to formation of plate meristem. The activity of meristem (perpendicular division to surface) results in increase in surface area but not in the thickness of the leaf. In the lamina, the cells of the plate meristem have a stratified arrangement that develops the epidermis, palisade and spongy tissue along with vascular bundle. The vascular bundle and their sheath development interrupt the regular arrangement of the cell layers in plate meristems. Thus in the final stage of the expansion of the leaf surface, the regular arrangement of cell layers becomes restricted to those areas of the lamina between the large lateral veins. The palisade parenchyma is one of the last tissue to cease growing and dividing. Since the growth of leaf takes place in all direction at different rates. The growth is called as anisotropic growth. It is controlled by genes and hormone (auxin) action.

Development of veins

The development of procambial strands of mid rib precedes that of lamina and it proceeds in acropetal direction. With the commencement of development of lamina, the procambial strands of large lateral veins and later of smaller veins ~~begins~~ to form gradually.

Genetic aspect of leaf development

Shoot apical meristem (SAM) is responsible for origin of leaves that are initiated in the peripheral zone of the shoot apex. KNOTTED1 (KN1) in Maize, KNAT1, STM1 in *Arabidopsis*, HBK1 in conifer, class of genes are responsible for leaf primordial initiation in plants. These genes are down regulated while the leaf primordial initiation occurs in SAM.

Leaf Arrangement

The leaves are arranged on stem in a specific order on the stem. The arrangement of leaves on a stem is called phyllotaxis (Greek; *phyllon* =leaf and *taxis* =arrangement). There are five different ways in which the leaves are arranged on plants. The most common types of phyllotaxis are as follows:

- **Alternate/Spiral**: when each node bear a single leaf and these leaves form a helical pattern around the stem with an angle of divergence between successive leaves of 137.5º for e.g. *Quercus, Croton, Morus alba* and *Hectorella caespitosa*.
- **Distichous:** When each node bear a single leaf and these leaves are disposed at 180º apart in two opposite ranks, as in grasses.
- **Opposite:** When leaves are present at 90º from each other in pairs at each node for e.g. *Acer* and *Lonicera*.
- **Decussate:** At each node if each successive pair of leaf is at right angle to the previous pair for e.g. in Labiatae, including *Coleus*.
- **Whorled:** when three or more leaves at each node. For e.g. in *Nerium oleander*, *Hydrilla* and *Alstonia.*

Phyllotaxy provides a proper display of the plant leaves so that all leaves can receive light and transpire well. Phyllotaxy provides an important diagnostic feature for identification of plants.

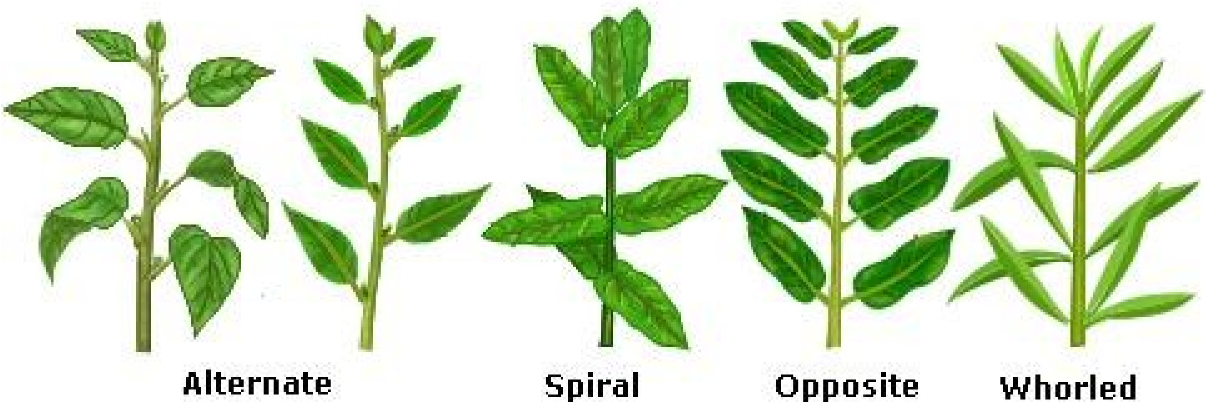

Figure: Phyllotaxis in plants.

Source: http://biology.tutorvista.com/plant-kingdom/leaf.html

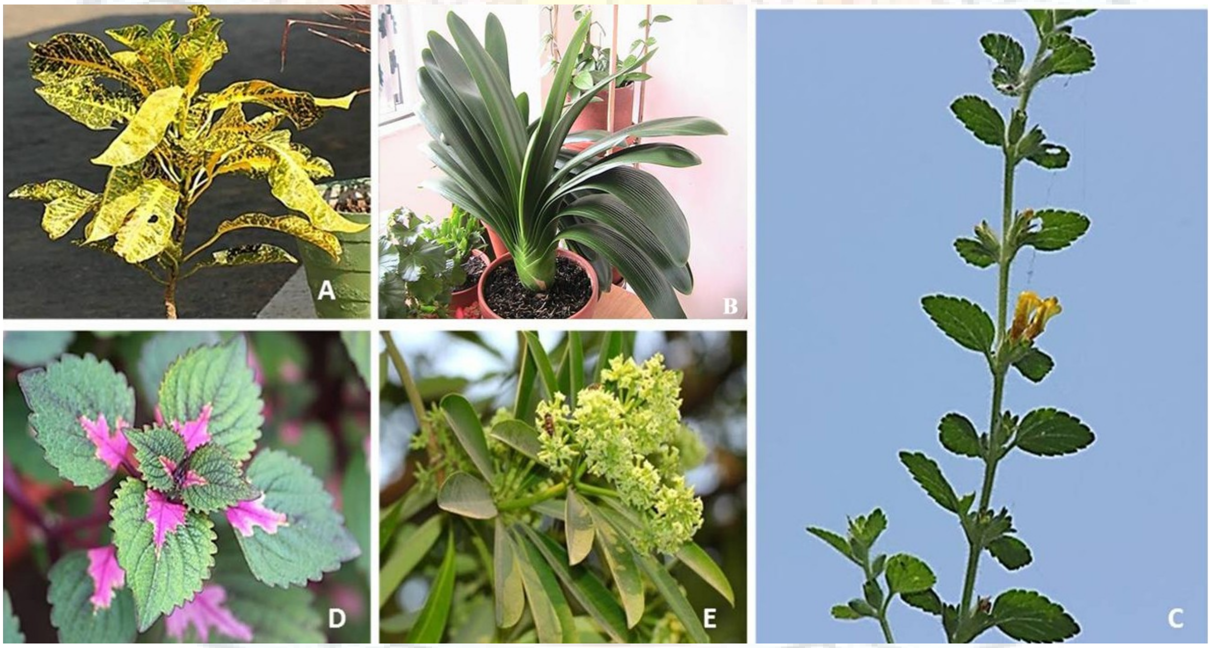

Figure: Arrangement of leaves: A) *Croton* sp. (alternate/spiral); B) Clivia (distichous); C) Opposite; D) *Coleus* sp. (decussate) and E) *Alstonia* sp. (whorled).

Source: Author;

B): http://en.wikipedia.org/wiki/File:Clivia-GreenPlants.ca.jpg

Type of leaves

Broadly the leaves are classified into two types: simple and compound leaf. Simple leaves are those in which one blade is present. Leaf may be incised to any depth, but not down to the midrib or petiole, e.g. Mango, China rose, *Ficus sp.*, etc.

On the other hand, compound leaf contains more than one blade and the leaf blade is incised up to the midrib or petiole, thus dividing it into several small parts, known as leaflets. Compound leaves are of two types namely, pinnately and palmate compound leaf. A compound leaf with leaflets that are arranged on either side of a central main stem or petiole is called as pinnate compound leaf but when a compound leaf with leaflets radiating from a common point at the end of the stem or petiole is called as palmate compound leaf.

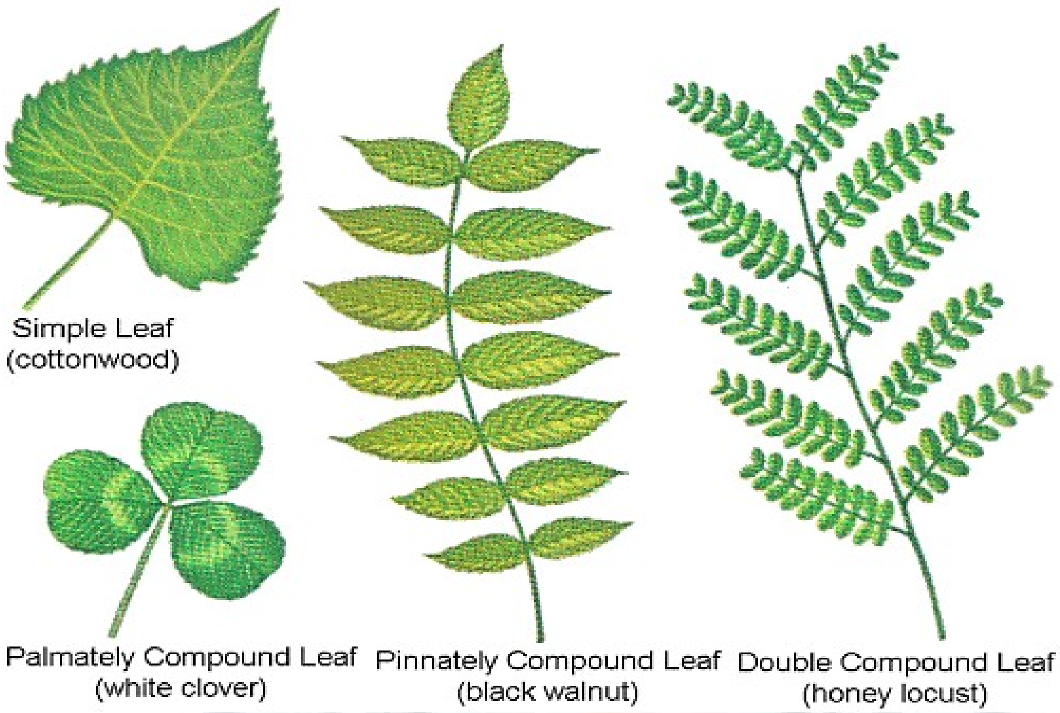

Figure: Type of leaves.

Source: http://www.robinsonlibrary.com/science/botany/anatomy/leafparts.htm

Pinnate compound leaves

They are of four types:

a) **Unipinnate**: In this type of leaf, division occurs only once and leaflets are directly attached on both sides of rachis. If the number of leaflet is even, then leaf is known as paripinnate for e.g. *Cassia fistula* and *Sesbania* but if the number of leaflet is odd, it is known as imparipinnate for e.g. Rose (*Rosa indica*) and Neem (*Azhadirachta indica*).

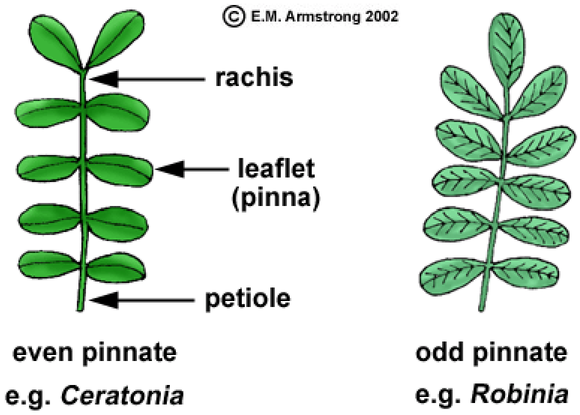

Figure: Diagrammatic representation of even and odd pinnate.

Source: http://www.1costaricalink.com/costa_rica_trees/glossary.htm

b) **Bipinnate**: A twice pinnate compound leaf e.g. *Acacia, Gulmohar* and *Mimosa.*

c) **Tripinnate**: A thrice pinnate compound leaf e.g. *Moringa.*

d) **Decompound**: A compound leaf, which is more than thrice pinnate e.g. Carrot and Coriander.

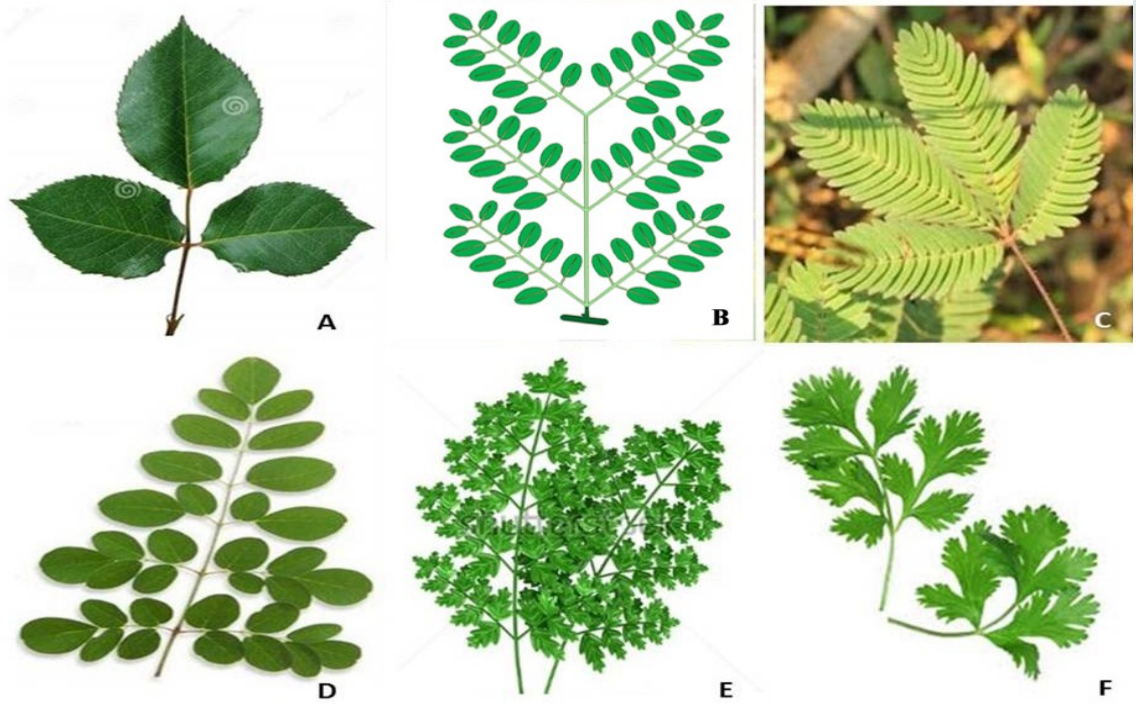

Figure: Pinnate compound leaves: A) Rose (Unipinnate imparipinnate); B) *Cassia* (Unipinnate paripinnate); C) *Mimosa* (Bipinnate) D) *Moringa* (Tripinnate) E) Carrot (Decompound) and F) Coriander (Decompound).

Source: A) http://www.superstock.com/stock-photos-images/1566-399479

B) http://www.picstopin.com/259/ofdicotleaf/http:||www*3qindia*com|3q|img|10|266*jpg/

C) http://commons.wikimedia.org/wiki/File:Leaf_morphology_type_bipinnately-compound.png

D) http://thehealthcolumn.com/tips/moringa-leaves/

E) http://www.shutterstock.com/pic-58866161/stock-photo-two-carrot-leaf-isolated-on-white.html

F) http://usesofherbs.com/coriander

Palmate compound leaves are of following types -

a) **Unifoliate**: When single leaflet is present e.g. Lemon.
b) **Bifoliate:** When two leaflets are present e.g. *Bauhinia* and *Bignonia.*
c) **Trifoliate:** When three leaflets are attached e.g. *Oxalis*, *Aegle* and *Trifolium*
d) **Tetrafoliate:** When four leaflets are attached to the petiole e.g. *Marselia*.
e) **Multifoliate:** when more than four leaflet are found, then leaf is called multifoliate palmate compound leaf e.g. silk cotton.

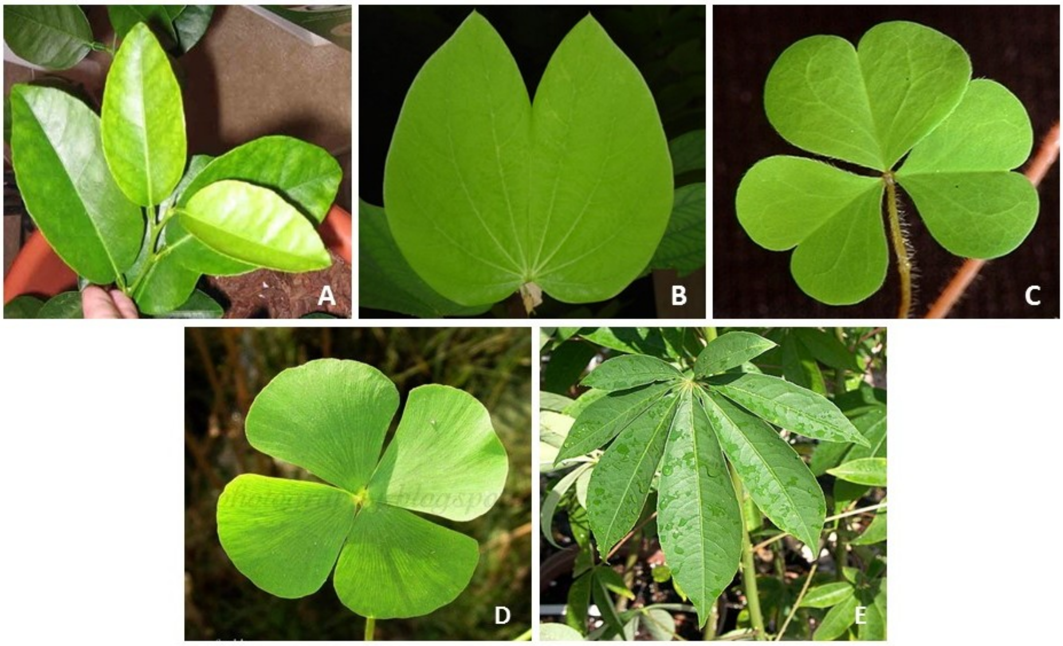

Figure: Palmate compound leaves A) Lemmon (unifoliate); B) *Bauhinia* (bifoliate); C) *Oxalis* (trifoliate); D) *Marselia* (tetrafoliate) and E) Silk cotton (multifoliate).

Source: A) http://forums.gardenweb.com/forums/load/citrus/msg0111041729188.html

B) http://en.wikipedia.org/wiki/File:Bauhinia_leaf.jpg

C) https://gobotany.newenglandwild.org/species/oxalis/corniculata/key/dichotomous

D) http://pk-photography.blogspot.in/2012/01/water-clover.html

E) http://toptropicals.com/cgibin/garden_catalog/cat.cgi?uid=ceiba

Sometimes occurrence of more than one type of leaves on the same plant is seen. This is called as heterophylly. It is of three types:-

- **Developmental** or places on the same plant for e.g. Mustard*, Sonchus* and *Eucalyptus.*
- **Environmental Heterophylly**: It is an aquatic adaptation observed in rooted emergent hydrophytes. The submerged leaves differ morphologically from the floating and aerial leaves for e.g. *Limnophila, Heterophylla, Ranunculus aquatilis* and *Sagittaria.*
- **Habitual Heterophylly**: Due to habit mature leaves differ in their shape and incissions for e.g. *Artocarpus* (Jack fruit).
- **Heterophylly**: Leaves of different forms and shape occur at different period

Modification of leaves

Leaves may show diverse modification which are as following:

a) Leaf tendril: The whole leaf is modified into thin thread like coiled structure called as leaf tendril. As they come into contact with any object, they coil around it and help the plant in climbing for e.g. *Lathyrus* aphaca (wild pea). Tendril may be formed by modification of whole leaflet or part of it. Tendril formed by terminal leaflet (*Pisum sativum*), Leaf apex (*Gloriosa*), Petiole (*Clemantis*) and stipule (*Smilex*).

b) Leaf spine: Leaves or any part of the leaflet gets modified into pointed spine called as leaf spine for e.g. *Asparagus, Opuntia, Aloe* and *Argemone*. These are used as defense weapon by plants.

c) **Leaf scale:** When the leaves become thin, dry and form a membrane or paper like structure which helps in protecting axillary buds as in *Ficus*, *Tamarix*, *Ruscus* and *Casurina* is called as leaf scale.

d) **Leaf pitcher:** Leaves of some plants are modified to pitcher shape e.g. *Nepenthes* and *Dischidia* and used in capture, killing and digestion of insects in insectivorous plants.

e) **Leaf bladder:** Leaves are modified into bladder like structure (*Utricularia*).

f) **Leaf Hooks:** Terminal leaflets are modified into curved hooks which helps the plant in climbing e.g. *Argemone, Opuntia, Aloe* and Cat's nail (*Bignonia unguis – cati*).

g) **Phyllode:** Petiole may be modified into flat structure, functioning as a normal leaf e.g. Australian acacia (*Acacia auriculiformis*).

h) **Fleshy leaves:** These leaves store food material for e.g. Onion and Garlic.

Figure: Modification of leaves: A) *Lathyrus* (leaf tendril); B) *Opuntia* (leaf spine); C) *Ruscus* sp. (leaf scale); D) *Dischidia* sp. (leaf pitcher); E) *Utricularia* sp. (leaf bladder); F) *Bignonia unguis – cati* (leaf Hooks); G) *Acacia* sp. (phyllode) and H) Onion (fleshy leaves).

Source:

A) http://www.colourbox.com/image/close-up-tendrils-of-pea-image-2151234

B, C) Author: botany25@gmail.com

D) http://toptropicals.com/catalog/uid/Dischidia_rafflesiana.htm

E) https://gobotany.newenglandwild.org/species/utricularia/inflata/?key=dichotomous

F) http://herbaria.plants.ox.ac.uk/vfh/image/index.php?item=186

G) http://davesgarden.com/guides/articles/view/451/

H) http://en.wikipedia.org/wiki/Onion

Anatomy of dicot and monocot leaf

On the basis of anatomical differences, angiosperms show two types of leaf namely dorsiventral and isobilateral leaf. Interestingly few species show circular type of leaf as found in e.g. onion. Dorsiventral leaf is characteristic feature of dicot plants such as *Manifera indica* (Mango), *Ficus benghalensis* (Banyan) and *Nerium* sp.

Three types of tissues are present in leaf lamina namely epidermis, mesophyll and vascular bundles with diverse arrangements.

Dicot Leaf

Epidermis

Epidermis is present at the upper (adaxial) as well as lower (abaxial) surface of leaf. Mostly epidermal layer is uniseriate, composed of compact tabular cells. The outer surface of epidermal cells is cutinized but in case of multiserriate epidermis, the upper epidermal cells are more cutinized as compared to lower epidermal cells. In *Ficus* the upper epidermis is multilayered (generally three layered), where the uppermost layer is made up of isodiametric cells while lower two layers are made up elongated cells which are comparatively bigger in size. In contrast to *Ficus,* upper epidermis of *Nerium* leaf is also multiseriate but in each layer the cells are of same type except outer layer which in having slightly smaller cells. The upper epidermal layer contains some secretary tissue such as cystoliths which contain calcium carbonate crystals. Usually the lower epidermis is uniseriate in nature.

Stomata are distributed evenly on the lower epidermis (*Magnifera* and *Ficus)* but in case of *Nerium*, sunken stomata are observed, which are located in a cavity called as stomatal pit. The trichomes develop from the cells surrounding the pit provide an effective mechanism for reducing transpiration.

Mesophyll

The ground tissue of leaf consists of specialized tissue systems known as mesophyll, differentiated into two types of cells viz. palisade and spongy parenchyma cells.

Generally the palisade cells are seen towards the adaxial surface of the leaf. Below the epidermal cell these cells are columnar cells are present that possess no or very little intercellular space. Palisade cells contain abundant chloroplast and thus act as primary photosynthetic tissue. Single layer of palisade cells are present towards the lower epidermis in *Nerium* and even calcium oxalate crystals are also present in this lower layer of palisade cells. The palisade layers are two layered in *Magnifera* and *Ficus*, three to four layers in *Oleander* or *Nerium*.

The spongy cells occur towards the lower epidermis in *Mangifera* and *Ficus* or between the palisade cells in *Nerium*. Spongy cells are thin walled, irregular in shape, isodiametric, loosely arranged with conspicuous intracellular space between them. The number of chloroplast is fewer in mesophyll cells as compared to palisade cells. The spongy cells help in gaseous availability for photosynthetic machinery.

Conducting system

The conducting system consists of tissues present near or at the center of the midrib region. Shapes of conducting strands are of various types such as ring form, a crescent shaped ring or in the form of scattered patches. Within the ring shaped conducting strands parenchymatous cells are present in the center of the ring. The vascular bundles in the leaves are generally collateral and closed type with xylem lying on the upper side (adaxial surface) and phloem on the lower side (abaxial surface). The xylem is composed of various kinds of vessels, tracheid’s, phloem fibers and parenchyma cells. Xylem not only helps in conduction of water and mineral nutrients but also provide mechanical support to the leaves. The phloem is composed of sieve tubes, companion cells and phloem parenchyma cells. Phloem helps in translocation of prepared food materials from the mesophyll cells to different parts of the plant.

The structure of larger veins is more or less similar to that of midrib but it gets reduced in size and is simple in structure as it passes from the base of the leaf blade towards the apex or margins of the leaf. In smaller veins, identical pattern is found as in midrib. The mesophyll cells are so arranged around the veins to facilitate the conduction of materials in and out form the veins.

The larger vascular bundles of dicotyledonous leaves are surrounded by a bundle sheath with fewer numbers of chloroplast. Bundle sheath extension are made up of parenchyma and collenchyma cells and they are present towards the outer side of bundle which may even reach upto the epidermal layers present on the adaxial as well as abaxial side of the leaf. Bundle sheath extensions are seen in mid rib region where the vascular bundles are larger in size.

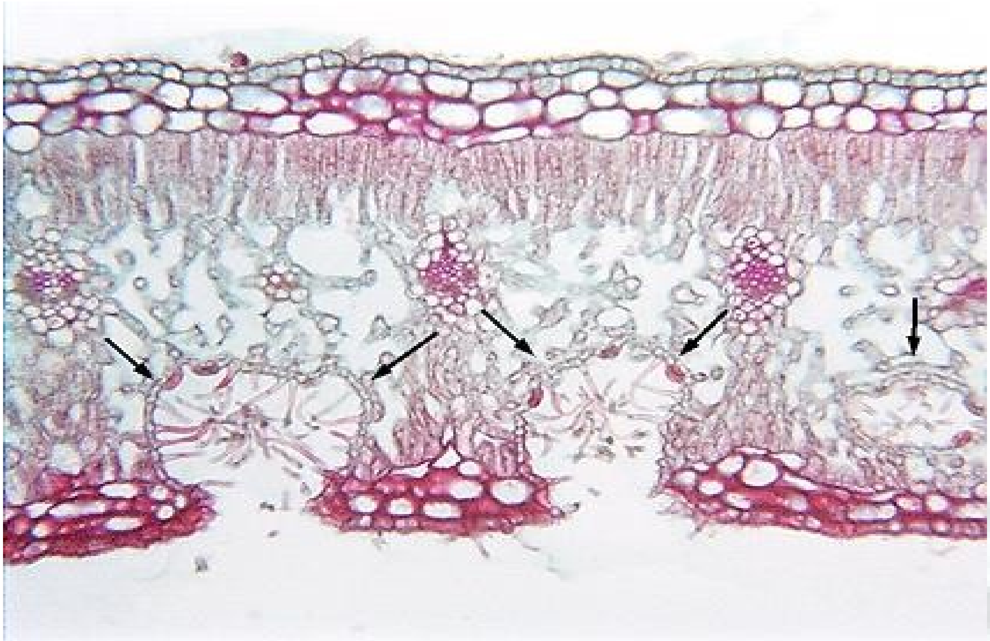

Figure: T.S. of oleander leaf (*Nerium oleander*). The arrows indicate three stomatal crypts: the crypts are large chambers in the mesophyll, covered with an epidermis that contains stomata as well as trichomes (hairs) that project into the crypt.

Source: http://www.sbs.utexas.edu/mauseth/weblab/webchap10epi/10.3-10.htm

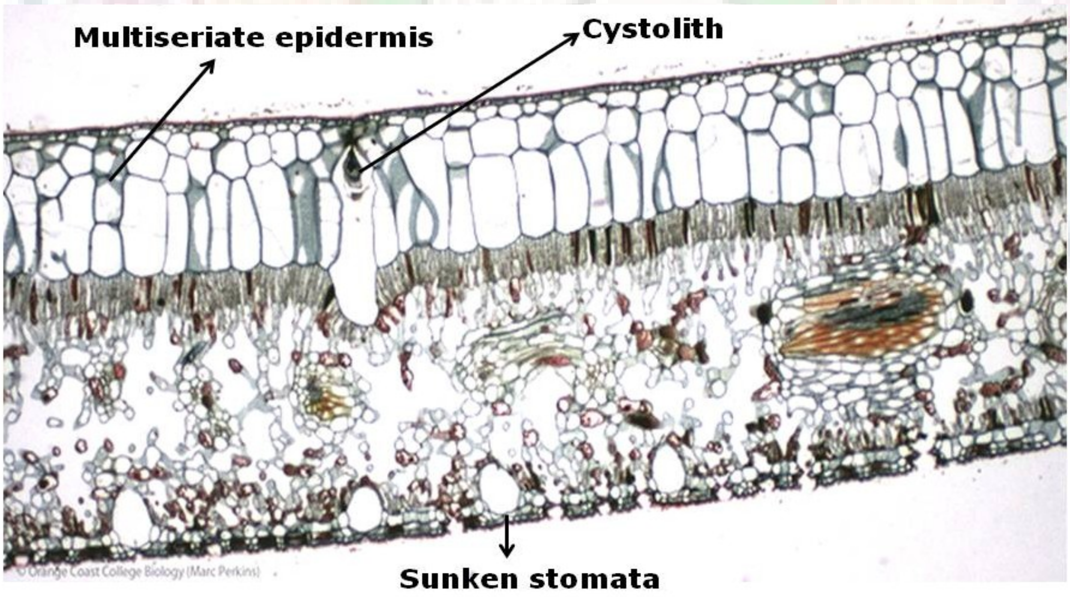

Figure: T.S. of *Ficus* leaf showing multiseriate epidermis, cystolith and sunken stomata.

Source:http://www.asknature.org/strategy/49f950fa30f8cd1472fcf52236291f23#.U8uY6vmSxCg

Monocot Leaf

Isobilateral type of leaves (iso = same and bi = two and lateral = side) are commonly found in the monocotyledons. The term isobilateral tells that both adaxial and abaxial surface of leaf have similar anatomical arrangements of leaf tissue. It is because mesophyll is hardly differentiated into palisade and spongy parenchyma cells.

Epidermis

The epidermis is generally uniseriate as in *Zea mays* and *Bambusa* but sometimes multiseriate (Date palm, *Phoenix sylvestris*). Epidermis is composed of more or less oval cells with cuticle on outer walls. The upper epidermis possesses some specialized large elongated cells called as motor cells or bulliform cells. These cells help in rolling down of leaf in order to avoid excessive loss of water when the wind velocity is high. It is important to note that bulliform cells are absent in date palm. Silica deposition is characteristic feature found in grass family leaves. Stomata are evenly distributed on both the surfaces of epidermal layer.

Mesophyll

Isobilateral leaf mesophyll cells do not show differentiation into palisade and spongy parenchyma and thus the tissue are composed of mainly isodiametric cells with intercellular spaces (mostly spongy type). Chloroplasts are abundantly present in these cells. In date palm, small groups of sclerenchyma cells occur in parallel series towards both the upper and lower epidermis.

Conducting strand

Vascular bundles are collateral and closed type as found in dorsiventral leaf but they are arranged in parallel series. These vascular bundles are of monomorphic or dimorphic (smaller and larger size) in nature. When dimorphic, the larger ones are fewer in number. Generally the vascular bundle contain xylem on the upper side and phloem on the lower side surrounded by parenchymatous cells known as bundle sheath cells. The bundle sheath cells contain plastids with starch grains. These plastids present in the bundle sheath cells lack grana or poor in grana but possess the machinery to fix the carbon dioxide with the help of enzyme RUBISCO (Ribulose-1, 5-bisphosphate carboxylase/oxygenase) and thus consequently forms starch. Absence of grana makes plastid nongreen and eventually the bundle sheath colourless. On the other hand, the mesophyll cells also have plastids with well-developed grana that generates high amount of ATP and NADPH (assimilatory power) and have special enzyme phosphoenol pyruvate carboxylase (PEPcase) that can capture the CO_2 very efficiently from the atmosphere and send trapped CO_2 and assimilatory power to bundle sheath cells for fixation. Sometimes in plants like date palm the larger vascular bundles are surrounded by sclerenchymatous bundle sheath while the small vascular bundle also show presence of few sclerenchyma cells at the tip or end of the bundles.

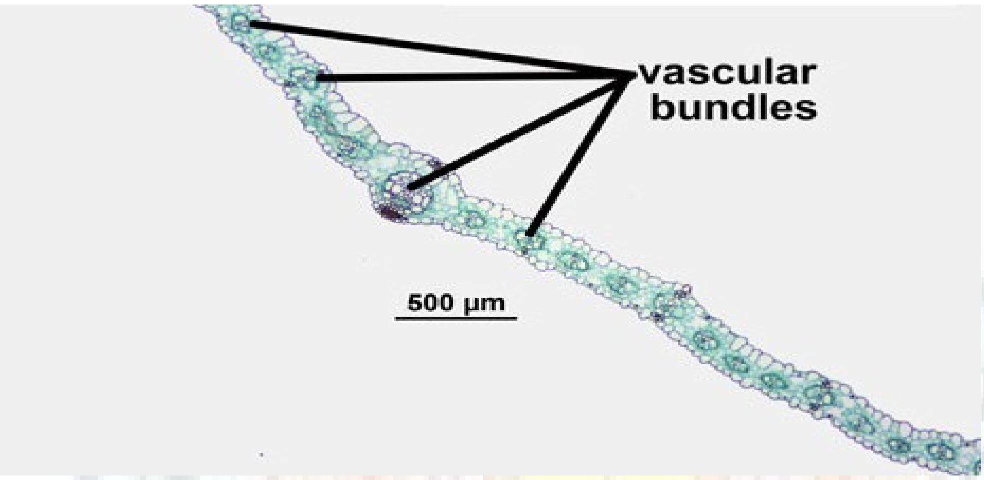

Figure: T.S. of *Zea mays* leaf.

Source: http://www.deanza.edu/faculty/mccauley/6a_site_images/zealeaf-4x-500.jpg

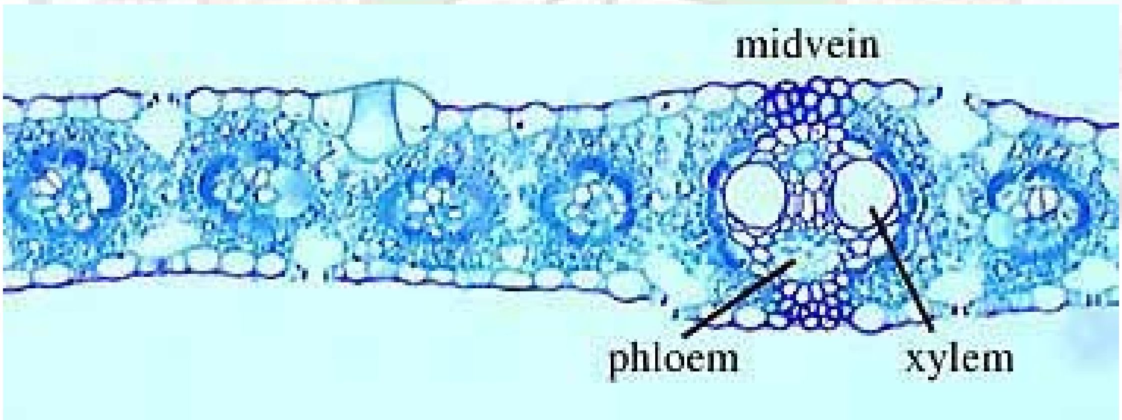

Figure: T.S. of *Zea mays* leaf (a portion enlarged).

Source: http://www.ucmp.berkeley.edu/IB181/VPL/Ana/AnaP/Ana22l.jpeg

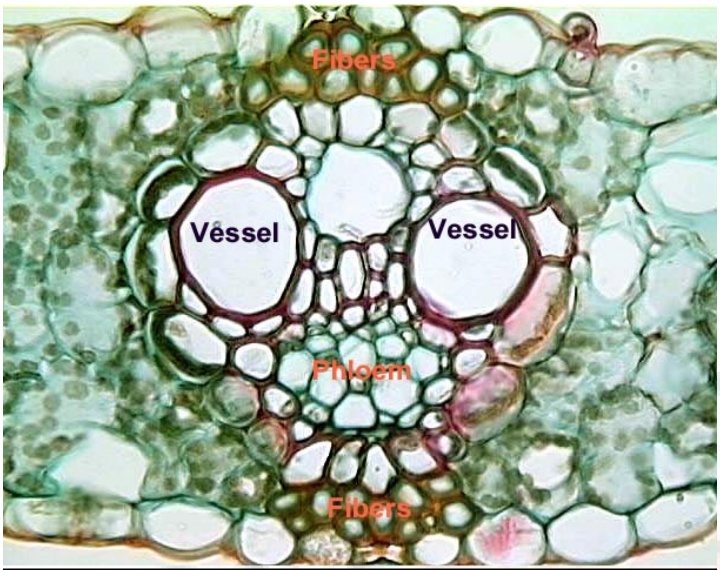

Figure: T.S. of *Zea mays* leaf showing a vascular bundle (enlarged).

Source: http://www.lima.ohio-state.edu/biology/images/zealeaf2.jpg

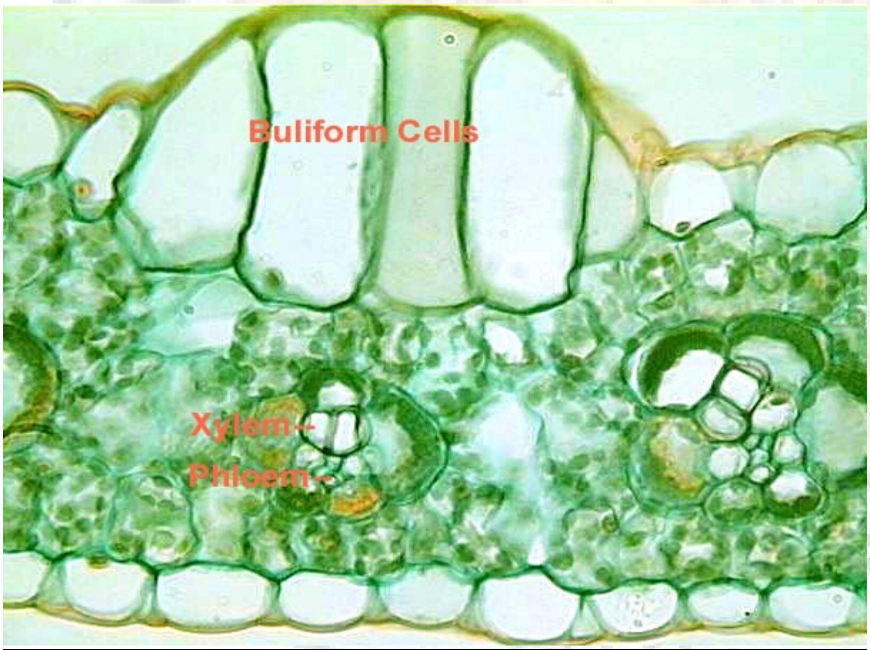

Figure: Monocot leaf showing specialized epidermal bulliform cells.

Source: http://www.lima.ohio-state.edu/biology/archive/leaves.html

Kranz Anatomy

Photosynthesis is most an important phenomena for existence and diversity of life forms on earth. Leaf morphology, anatomy and orientation controls the absorption of light for photosynthesis. Leaves and chloroplast adjust according to the availability of light and this can be observed in more green or less green leaves and alteration in shape and size of leaves. Plant not only modifies structural or anatomical aspects of leaves but also changes the functional aspect according to its requirement. The best example of anatomical and functional modification is seen in leaves of C_4 plants known as Kranz anatomy.

Kranz anatomy is seen in leaves of higher dicot and monocot plants. Kranz, a German term means wreath. Kranz anatomy is generally associated with plants showing C_4 pathway for photosynthesis. In these plants vascular tissue system is surrounded by two types of photosynthetic cells-the bundle sheath cells and the mesophyll cells. Bundle sheath cells surrounding the vascular bundles are large, green, thick-walled and ~~acts~~ as intermediate between vascular bundle and mesophyll cells. There are fewer number of green mesophyll cells often extended radially from the bundle sheath. Several plasmodesmata connections are present between mesophyll and bundle sheath cells. The bundle sheath cells are unique because chloroplast are centrifugally arranged which have unstacked thylakoid or lacks grana and the stroma is rich in starch granules. Contrary to this mesophyll cells possess randomly arranged chloroplasts are generally devoid of starch in stroma and thylakoid are stacked or well developed grana is present. Haberlandt called this type of arrangement as Kranz leaf anatomy.

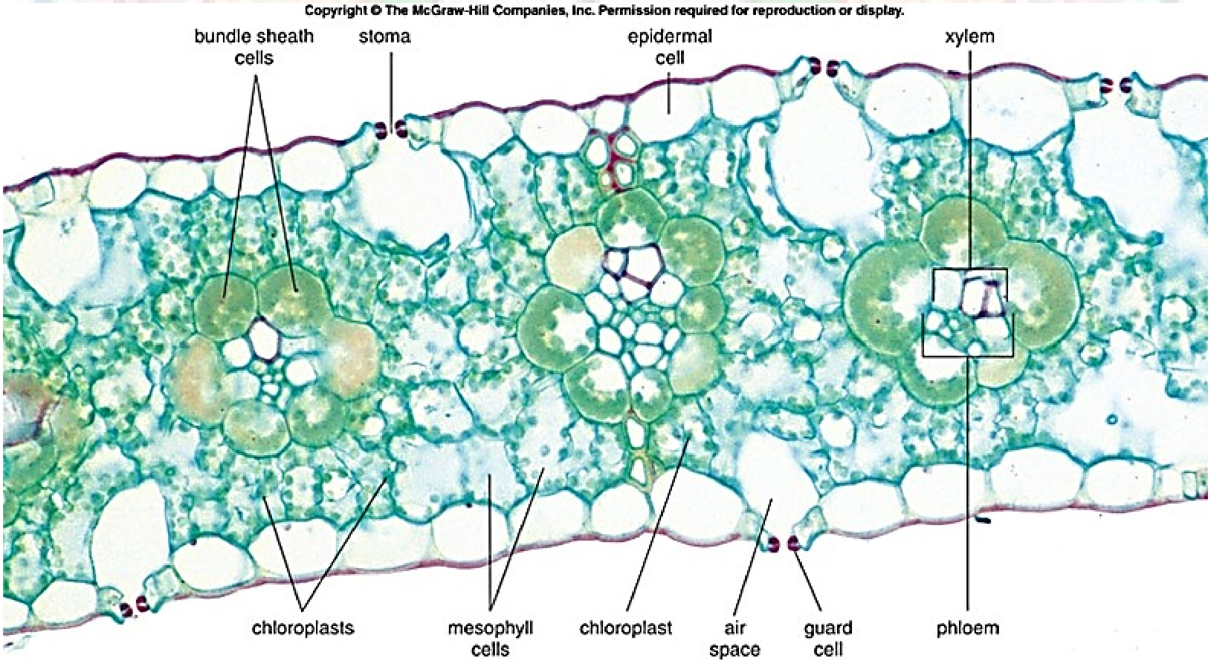

Figure: T.S. of leaf showing kranz anatomy.

Source**:** http://www.studyblue.com/notes/note/n/carbon-fixing-reactions-lecture-12/deck/1297275

C_4 cycle without Kranz anatomy !

- ✓ Generally C_4 plants shows kranz anatomy but there are few exceptional species for eg. *Borszczowia aralocaspica and Bienertia cyclopteria* (Chenopodiaceae) growing in Central Asia and growing from East Anatolia eastward to Pakistan respectively. In the above species the C_4 cycle operate without involving bundle sheath tissue. The entire C_4 pathway operates within individual, structurally and biochemically polarized chlorenchyma cells rather than in a dual cell system (Mesophyll and bundle sheath cells).
- ✓ Diatoms also perform C_4 photosynthesis in a single cell.

Kranz anatomy ensures spatial compartmentalization of enzyme that are essential for carbon dioxide fixation in C_4 pathway. Presence of well-developed grana in mesophyll cell generates abundant assimilatory power in the form of NADPH and ATP which is utilized in CO_2 fixation into oxaloacetate from PEP (Phosphoenol pyruvate carboxylase) via PEPcase. Thus oxaloacetate is the first C_4 product which is unstable and thus gets converted to malic acid. On the other hand bundle sheath cell are specialized to function in fixation of CO_2 released after decarboxylation. The intercellular bundle sheath cell organelle and cytoplasm are also rich in enzyme decarboxylase such as NADP-Malic enzyme in chloroplast, NAD-Malic enzyme in mitochondria and PEP carboxykinase in cytosol. The enzyme phosphoenol pyruvate carboxylase (PEPCase) present in the mesophyll cells helps in trapping CO_2 from environment via stomatal pore. Trapped CO_2 is then transferred to bundle sheath cell where enzymes for Calvin cycle (C_3 cycle) are present. This transfer is called as concentration of CO_2 in bundle sheath cells. Due to concentration of CO_2 the enzyme RUBISCO does not show photorespiration that is usually exhibited in normal C_3 pathway plants. Glucose is ultimately seen as starch grain or transported to other part of plant body. The spatial arrangement of cells with their respective enzymes in kranz anatomy makes the C_4 pathway very efficient and successful over the C_3 pathway.

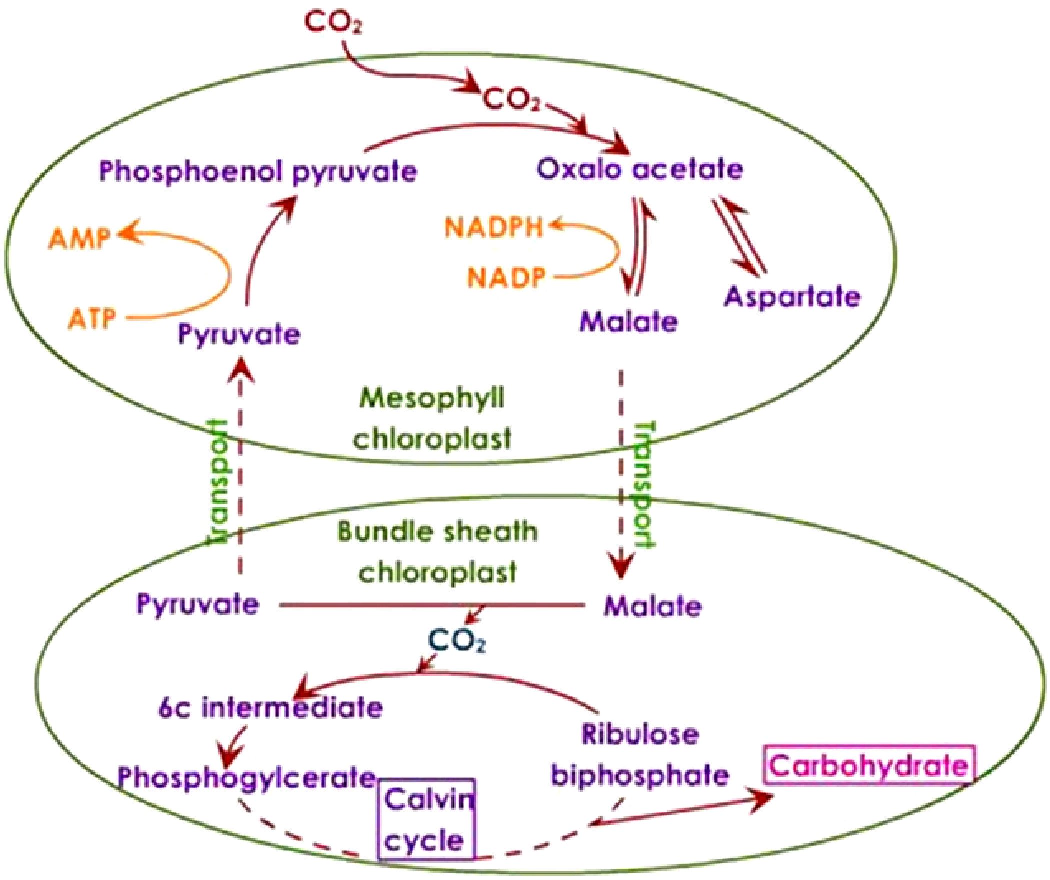

Figure: A Schematic representation of Hatch and Slack pathway (C_4 Cycle).

Source: http://www.tutorvista.com/content/biology/biologyiv/photosynthesis/carbon-pathway.php

Anatomy of petiole

It is a stalk like structure by which lamina remains attached to ~~with~~ the stem. When petiole is absent, leaves are called as sessile. Petiole shows various shapes in cross section such as circular, triangular, circular with ridges and furrows etc. the anatomy of petiole is explained by taking few examples.

Cucurbita

Cucurbita petiole shows distinct ridge and furrows and a hollow cavity in the central region in the transverse section. The internal structure shows following important regions

- Epidermis
- Ground tissue

- Vascular bundles

The epidermis is uniseriate made up of tubular cells with cuticle present on outer wall. Multicellular hairy outgrowths are present on epidermis. Ground tissue consists of tissue system excluding epidermis and vascular bundle. It consists of collenchyma cells with thick corners present below epidermis in patches only below the ridges. Rest part is filled by thin walled parenchyma cell with distinct intercellular space. Vascular bundles are discrete, arranged in a ring and present below the ridge. Individual vascular bundles are bicollateral and open type where the xylem is surrounded on both side by phloem (. 22). A big cavity is present in the central region.

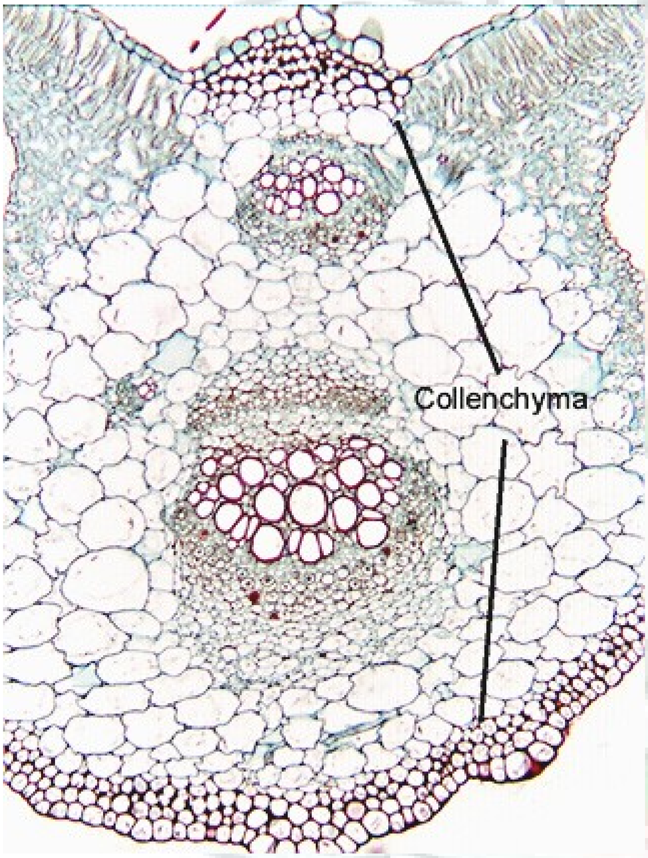

Figure: T.S. petiole of *Cucurbita pepo*.

Source**:** http://www.kbg.fpv.ukf.sk/studium_materialy/morfologia_rastlin/webchap4coll/4.2-1.htm

Sunflower (*Helianthus annus*)

Sunflower (*Helianthus annus*) petiole appears as semicircle with groove at one side. The epidermis is uniseriate, consists of rectangular cells that makes the outer most layer.

Epidermis possess hairy outgrowth (trichomes). Below the epidermis, collenchyma cells are present in patches (not in continuous ring) and the gap is filled with chlorenchyma cells. This ring of cells makes the hypodermis. Below hypodermis ground tissue is present which is made up of thin walled parenchymatous cells with distinct spaces. Occurrence of mucilage canal is a distinctive feature. The vascular bundle are embedded within the ground tissue, these vascular bundle are large and small. Each vascular bundle are collateral and closed type with xylem on the inner side and phloem on the outer side.

Nymphaea

Nymphaea (water lily) a floating hydrophyte, is characterized by presence of large air chamber, branched trichosclereids or internal hairs with deposition of calcium oxalate crystals. Vascular bundles are small, reduced and scattered in nature. Transverse section of petiole shows epidermis, ground tissue and vascular bundles.

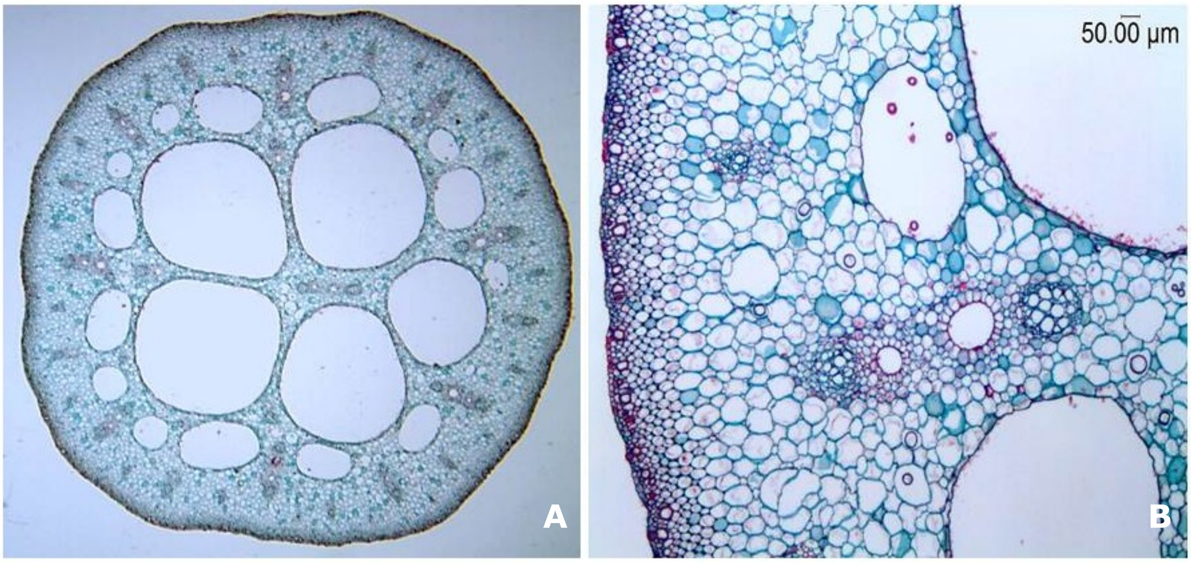

Figure: Transverse section of petiole of *Nymphaea odorata* A) outline diagram and B) A part enlarged.

Source:A)http://phytoimages.siu.edu/imgs/Cusman1/r/Nymphaeaceae_Nymphaea%20odorata_47213.html

B)http://www.phytoimages.siu.edu/imgs/Cusman1/r/Nymphaeaceae_Nymphaea%20_odorata_47214.html

The epidermis is uniseriate, consisting of rounded cell with little cutinization on outer walls. Epidermal cells contain unbranched hairs. Chloroplasts are present in epidermal cells that help in efficient photosynthesis. Below epidermis two to three layer of collenchymas cells are present which constitute the hypodermis. These collenchymatous cells have thickened corners. Ground tissue is made up of thin walled parenchyma cells. There are large numbers of air chambers present which contain needle shaped trichoscleroids often with deposition of calcium oxalate. The vascular bundle are poorly developed and scattered in the ground tissue. The xylem vessels usually break down, thus are poorly developed. Xylem is represented by single lacuna but phloem elements are normal. The vascular bundles are of two types: central and peripheral vascular bundles. Central vascular bundle is large and contains two groups of phloem within central xylem but peripheral vascular bundles are small with only one outer phloem and xylem.

Summary

Leaves are one of the most important organs of plants. They are generally green and flat structure. They capture the light or solar energy and convert them into chemical energy with the help of chlorophyll molecule that are present in chloroplast through a process known as photosynthesis. The leaf performs diverse function such as photosynthesis, transpiration and storage.

A typical foliage leaf of an angiosperm consists of a leaf base, the petiole (leaf stalk), a lamina (leaf blade) and stipules. Broadly the leaves are classified into two types: simple and compound. The development of leaf occurs from the leaf primordia which arise from shoot apex. Its development occurs in many stages. The leaves are arranged in a specific order on the stem. The arrangement of leaves on a stem is called phyllotaxis. Leaves show diverse modification such as leaf tendril, leaf spine, bladder, pitcher and phyllode.

On the basis of anatomical structure, two types of leaves have been recognized in angiosperms, dorsiventral and isobilateral leaves. The dorsiventral leaves are mostly found in dicotyledon group of angiosperms and grow in horizontal direction with distinct upper (adaxial) and lower (abaxial) surfaces. Isobilateral types of leaves are commonly found in the monocotyledons.

Plants not only modify structural or anatomical aspects of leaves but also change the functional aspect or both. The best example of anatomical and functional modification is seen in adaptation of leaves of C_4 plants as Kranz anatomy that provide some evolutionary advantage over C_3 plants.

General Anatomy of Leaf

Glossary

Abaxial: Directed away from the axis, refers to lower surface of leaf.

Adaxial: Directed toward the axis and opposite of abaxial. It is used with regard to a leaf upper or "ventral" surface.

Bundle sheath: Layer or layers of cells enclosing a vascular bundle in a leaf; may consist of parenchyma or sclerenchyma.

Guard cells: A pair of cells flanking the stomatal pore and causing the opening and closing of the pore by change in turgor.

Hydathode: A structural modification of vascular and ground tissues found in a leaf that permits the release of water through a pore in the epidermis.

Lamina of leaf: Expanded part of the leaf also called *blade* of leaf.

Leaf buttress: A lateral protrusion below the apical meristem constituting the initial stage in the development of a leaf primordium.

Leaf fibers: Technical designation of fibers derived from monocotyledons, chiefly from their leaves.

Leaf primordium: A lateral outgrowth from the apical meristem that eventually become a leaf.

Leaf sheath: The lower part of a leaf that invests the stem more or less completely.

Mesophyll: Photosynthetic parenchyma of a leaf blade located between the two epidermal layers.

Major veins: Larger leaf vascular bundles, which are associated with ribs; they are largely involved with the transport of substances into and out of the

Palisade parenchyma: Leaf mesophyll parenchyma characterized by elongated form of cells and their arrangement with their long axes perpendicular to the surface of the leaf.

Petiole: Stalk attaching the leaf blade to the stem.

Phyllotaxy (phyllotaxis): Arrangement of leaves on the axis of a shoot.

Phyllode: When the petioles become flattened and widened and start functioning as leaf and the true leaves may become reduced or vanish altogether.

Stoma (pl. stomata): An opening in the epidermis of leaves and stems bordered by two guard cells and serving in gas exchange.

Stomatal complex: Stoma and associated epidermal cells that may be ontogenetically and/or physiologically related to the guard cells. It is also called as stomatal apparatus.

Stomatal crypt: A depression in the leaf, the epidermis of which bears stomata.

Exercise

Q.1. Write short note on:

a) Kranz anatomy
b) *Ficus* leaf
c) Petiole
d) Phyllotaxy
e) Leaf functions

Q.2. Distinguish between:

a) Monocot and Dicot leaf
b) Bulliform and Epidermal cell
c) Bundle sheath cell and Mesophyll cell
d) Phyllode and Phyllaclade
e) Palisade and Spongy parenchyma
f) Tendril and Spine
g) Simple and Compound leaf
h) Isobilateral and Dorsivental leaf

Q.3. Describe the general anatomy of leaf.

Q.4. What is phyllotaxy and write its significance?

Q.5. Describe leaf development in angiosperms.

Q.6. What is kranz anatomy and write its significance.

Q.7. List the types of modification occur in plant leaves with examples.

Q.8. Discuss the anatomical features of dicot leaf

Q.9. Discuss the anatomical feature of grass leaf.

Q.10. What is heterophylly and write it importance in plant?

Multiple Choice Questions

Q.1. Bulliform cells are found in:

a) Bulb of onion

b) Dicot root

c) Stem of Monocot

d) Leaf of monocot.

Correct Answer:

d) Leaf of monocot

Resource/Hint/feedback for the wrong answer

a) Onion bulb is a short stem with fleshy leaves or leaf bases which function as food storage organs during dormancy.

b) Bulliform cells are characteristic feature of monocot leaves.

Q.2. The amount of cuticle is:

a) High in leaves from dry climate plants

b) High in leaves from wet climate plants

c) Both

d) None of the above.

Correct Answer:

a) High in leaves from dry climate plants

Feedback for answer:

Plants develop thick cuticle on leaves of dry climate for protecting themselves from huge loss of water through transpiration.

Resource/Hint/feedback for the wrong answer

Plants from wet climate do not suffer from high loss of water through transpiration thus not need thick cuticle.

Q. 3. Characters shown by dorsiventral leaf is/are:

a) Palisade layer present on both the side (adaxial and abaxial) of leaf

b) Palisade layer present on adaxial surface

c) Palisade layer present on abaxial surface

d) None of the above.

Correct Answer:

(a) Palisade layer present on both the side (adaxial and abaxial) of leaf.

Feedback for answer:

Palisade layer helps in the adaptation according to the environmental condition and help in harvesting light.

Resource/Hint/feedback for the wrong answer

Palisade layer is not present either on adaxial surface or on abaxial surface

Q.4. Phyllode, a leaf modification occurs in Australian acacia meant for photosynthesis shows adaptation to:

a) Xerophytic condition

b) Mesophytic condition

c) Halophytic condition

d) None of the above.

Correct Answer:

a) Xerophytic condition.

Feedback for answer:

In the Australian acacia, the leaflets are suppressed, and the leaf-stalks (petioles) become vertically flattened in order to serve the purpose of leaves. These are known as "phyllodes". The vertical orientation of the phyllodes protects them from intense sunlight in xelophytic or drought/ dessert condition, since with their edges towards the sky and earth they do not intercept light as fully as horizontally placed leaves.

Resource/Hint/feedback for the wrong answer

Mesophytic condition has less water crisis for plants thus not needed such modification. The halophytic adaptations are seen in plants growing in saline water and have adaptation like vivipary and thick cuticle deposition on leaves.

Q. 5. The arrangement of leaves on branches are called as-

a) Phyllotaxy
b) Phyllotaxi
c) Phytotaxy
d) Phyllome

Correct Answer:

. b) Phyllotaxy

Feedback for answer:

Phyllotaxy or phyllotaxis is the term used for the arrangement of leaves on a plant stem.

Resource/Hint/feedback for the wrong answer

Phyllotaxi, phytotaxy the terms given are not correct. All types of leaf appearing on plant are called as Phyllome.

Q. 6: When two sides of mesophyll of a leaf are similar in structure, the leaf is said to be

a) Hypostomatous.

b) Mesophytic.

c) Dorsiventral

d) Isobilateral

Correct Answer:

d) Isobilateral

Feedback for answer:

An isobilateral leaf is usually vertically oriented to expose both surfaces to the sun. The leaves hang vertically to expose one face directly to the drying sun, then the other face.

Resource/Hint/feedback for the wrong answer

If the stomata are present only on the lower surface of the leaves. It is known as hypostomatous leaf. E.g. Mango, Oleander, Banyan. Meophytic leaves are large and thin compared to xerophytes sometimes having a large amount of stomata on the undersides of the leaves and a dark green colour. Dorsiventral leaves are flat, having distinct upper and lower surfaces. Read more: http://www.answers.com/topic/dorsiventral#ixzz36NwTyqtr

Q. 7. What is missing in the leaf showing Kranz anatomy?

a) Bundle sheath

b) Palisade layer

c) Stomata

d) Vascularization/ Vascular bundles

Correct Answer:

b) Palisade layer

Feedback for answer:

Mesophyll cells in leaf showing kranz anatomy are not differentiated into palisade and spongy parenchyma cells

Resource/Hint/feedback for the wrong answer:

Bundle sheaths are present around the vascular bundles. Stomata are present.

Q. 8: What is/are true about a monocot leaf-

a) Reticulate venation

b) Absence of bulliform cells from epidermis

c) Mesophyll not differentiated into palisade and spongy tissues

d) Well differentiated mesophyll.

Correct Answer:

c) mesophyll not differentiated into palisade and spongy tissues

Feedback for answer:

In general, monocot leaf mesophyll cells are not differentiated into palisade and spongy tissues like dicot leaves.

Resource/Hint/feedback for the wrong answer:

The upper epidermis contain some large cells in groups are called bulliform cells. Usually the venation pattern in monocot is parallel.

Q. 9: The protective outer layer on leaf, cuticle is secreted by:

a) Epidermal layer

b) Mesophyll cells

c) Palisade layer cells

d) Endodermis

Correct Answer:

a) Epidermal layer

Feedback for answer:

The fatty acid components of cutin is formed by epidermal protoplast in the E.R. and transported to the outer wall of epidermal cells.

Resource/Hint/feedback for the wrong answer:

Mesophyll cells are not involved in cuticle synthesis Palisade are not involved in cuticle synthesis Endodermis are not involved in cuticle synthesis

Q.10: *Nepenthes* (Pitcher plant), an endangered insectivorous plant found in khasi hills of Meghalaya and grows in nitrogen deficient soil. The leaf is transformed into pitcher like structure, which part of leaf is involved in formation of pitcher:

a) Petiole

b) Leaf apex or tip

c) Leaf lamina

d) Stipule

Correct Answer:

c) Leaf lamina

Feedback for answer:

In this plant, the leaf lamina is transformed into pitcher like structure and leaf apex forms the lid

Resource/Hint/feedback for the wrong answer:

Petiole and stipule are not involved in the formation of pitcher.

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