Structure, Development and Reproduction in Flowering Plants

Body Plan and Diversity in Form

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Every living organism has a fixed form and it is because of this reason that we are able to distinguish most of them just due to their external structure. Study of external morphology or external appearance of higher plants is necessary to describe the plants in an accurate fashion and to distinguish between almost similar looking plants. Therefore, the plants are identified by their morphological characters. Variation in plants is found not only in external forms but also in their anatomical characters which are represented by different types of tissue systems . Morphology along with anatomy constitute the base of studying pattern of life forms.

Life Span of Plants

On the basis of life span, plants are of three types: annuals, biennials and perennials.

a) **Annuals:** These plants complete their life-cycle in a single growing season which varies from a few weeks to a few months. They pass the unfavourable period in the form of seeds. Examples are wheat, pea and sunflower, etc.

b) **Biennials:** These plants complete their life-cycle in two growing seasons. In the first season; they grow only vegetatively and store food generally in the roots. In the second season, these plants grow at the expense of the stored food and form the flowering shoot bearing flowers, fruits and seeds. Then the plants die. radish, turnip, cabbage, etc. growing in cold areas.

c) **Perennials:** These plants continue to grow from a few (more than two) to several years and bear the flowers and fruits during specific seasons. These are called polycarpic when they bear the fruits every year e.g. mango, lemon, apple, date, etc. Some plants, such as *Agave* are called as monocarpic since they flower and fruit only once in their life after a long period of vegetative growth.

Habit of Plant

Depending upon the size, nature of the stem and duration or life span, the plants are classified into three main categories, the herbs, shrubs and trees.

a) **Herbs:** They are small plants with soft and pliable stems which normally grow to a height of less than 2m. Herbs may be annual (e.g. Wheat, Buttercup), biennial (e.g. Henbane) or perennial (e.g. *Canna*). The perennial herbs have either water conserving mechanism or possess underground stem which produces new shoots every year.

b) **Shrubs:** Plants are of medium height with perennial woody stems. A trunk is absent. Many stem branches of equal height arise from near the base. They are woody below and herbaceous near the apices. Shrubs are also called bushes, e.g. *Capparis*, Jasmine, Rose.

c) **Trees:** Plants are of great height with a thick woody main stem called trunk. The trunk may remain unbranched when it is called caudex or columnar e.g. Palm. In excurrent form the trunk produces narrow lateral branches which do not compete with the former. The appearance is corm-like, e.g. *Pinus, Casuarina, Eucalyptus*. In deliquescent type the trunk disappears after some distance so that the crown appears dome shaped e.g. *Dalbergia, Banyan*.

Parts of a flowering plant

It has a long cylindrical axis or plant axis which is differentiated into above ground shoot system and underground root system. Root system consists of root and its branches. Shoot system is made up of stem, branches, leaves, flowers, and fruits containing seeds. The different structures borne on the plant axis are called organs. There are two types of plant organs, vegetative and reproductive. Vegetative organs take part in nutrition, growth and maintenance of plant body while the reproductive organs are meant for formation of new plants. Vegetative organs are three in number – root, stem and leaves. Reproductive organs are also of three types- flower, fruits and seeds .

1. **Root:** It is the underground nongreen part of the plant that anchors the plant to the soil and takes part in absorption of water as well as minerals. The root system consists of main or tap root, its branches or secondary roots, tertiary roots, etc. The finer root branches are called rootlets and the tip is covered by a root cap. Behind the tip are present a number of fine outgrowths called root hairs.
2. **Stem:** It is commonly the above ground and erect part of the plant with lateral branches. At intervals, the stem and its branches possess swollen areas or nodes. Leaves are borne in the region of nodes. Part of the stem between two adjacent nodes is called internode. The angle between the leaf and the upper or younger part of stem is called axil. It bears an axillary bud which later on develops into a branch or axillary branch. Growth of the stem is accomplished through a bud present at its tip. It is known as apical bud.
3. **Leaf:** It is a green dissimilar lateral outgrowth which develops on the stem or its branch in the region of node. A leaf has three parts- leaf base, petiole and lamina. Lamina or leaf blade is specialized for photosynthesis. It is also the main seat of transpiration.
4. **Flower:** It is a specialized and condensed shoot that takes part in sexual reproduction. A flower has broad surface called thalamus. The latter bears four types of structures- sepals (green), petals (coloured), stamens (microsporophylls) and carpels (megasporophylls). Sepals and petals are nonessential floral organs while stamens and carpels are essential floral organs. A stamen has broad terminal anther that contains tiny structures named pollen grains or microspores. A carpel has receptive tip or stigma, a stalk-like style and a basal swollen ovary containing one or more oval structures termed ovules.
5. **Fruit:** It is the ripened ovary. Fruit has a wall or pericarp and one or more seed.
6. **Seed**: It is a ripened ovule. Seed has an embryo, a food reserve and protective covering called seed coat. The embryo has an axis (embryo axis or tigellum) and one or two seed leaves called cotyledons. One end of embryo axis possesses plumule or future shoot. The other end has radicle or future root. Radicle often bears a root cap at its tip. Plumule is protected by few small leaves.

The portion of the embryo axis lying between the cotyledons and the plumule is called epicotyl while the one between cotyledons and the radicle is termed as hypocotyl.

MORPHOLOGY OF ROOT

Root is the non–green, cylindrical, axis of the plant that normally grows downwards into the soil. It is the first structure that comes out when a seed is placed in the soil. It is branched, the branching being endogenous i.e., developing from the deeper pericycle. It is not distinguished into nodes and internodes and does not bear leaves and buds.

The roots absorb water and mineral nutrients from the soil. They also fix the plant in the soil and there by hold the shoot firmly. These often serve as store house of the food material.

Characteristics of Root

Roots may be distinguished from the other plant organs by the following characteristics:

1. They are non-green, cylindrical organs that constitute the descending axis of the plant.
2. They do not bear leaves and buds.
3. They are not distinguished into nodes and internodes.
4. They possess root cap. However, roots in aquatic plants possess root pockets in place of root caps
5. They bear root hair in the root hair zone.
6. They are positvely hydrotropic and geotropic.
7. They are negatively phototropic.
8. They branch laterally,and the branches are endogenous in origin.
9. Their primary function is to fix the plant firmly in the soil and absorb water and mineral nutrients. However, in floating or submerged aquatics (e.g. *Myriophyllum, Ceratophyllum, Utricularia*), these two functions are not critical, and therefore, the root system may be poorly developed or totally absent.

Parts of A Typical Root

The following parts can be distinguished in a typical root :

1. **Root cap:** Root cap is thickened, protective cap- like structure present at the tip of root apex, without it the under root would be unable to penetrate the hard soil. It protects the young growing apex of roots in all the terrestrial plants. The cells of root cap secrete mucilage which lubricates the passage of root through the soil. When root pushes deeper into the soil particles, its outer cells are continuously peeled off and replaced by new cells formed from root meristem.
2. **Meristematic zone or zone of cell division:** It is a small region and about 1mm long located behind the root cap (sub-terminal). It represents the growing point having actively dividing meristematic thin walled cells, dense cytoplasm and prominent nucleus. This region adds new cells and is responsible for longitudinal growth of the root. It also absorbs mineral salts.
3. **Zone of elongation:** It lies just above the meristematic zone and is about 5mm long. The cells of this zone do not divide, and elongate rapidly. These cells possess the power of absorption of water and mineral salts from the soil. In cells of this zone, small vacuoles develop and later the vacuoles fuse to from one large central vacuole filled with cell sap.
4. **Zone of cell maturation (differentiation):** It is called as root hair maturation zone. Large number of unicellular root hairs are present which mainly absorb water and minerals from soil. It is the major part of root. The walls of cells are not elastic. As the cells of root hair zone become mature the root hairs shrivel and become non-functional. The enlarged cells undergo maturation and differentiation into different types of primary tissues of the root i.e. cortex , endodermis , xylem, phloem etc.
5. **Region or Zone of mature cells:** It forms the bulk of the root. The cells of this region do not undergo any further change. The outermost layer of this region has thick walled or impermeable cells. So this region cannot help the root in water absorption. Its only function is to anchor the plant firmly in the soil. Lateral roots also arise from the interior of this region.

Kinds of Root Systems

The roots alongwith their branches constitute the root systems. There are two types of root system, tap and adventitious . The tap root system is more common in dicots while adventitious root system is more prevalent in monocots.

1. **Tap root system:** It is a mass of roots which develops from the radicle of the embryo . It consists of a tap root, secondary root, tertiary roots and rootlets. The radicle itself grows up directly into the main or primary root. The persistent primary root is known as tap root. It is usually the most prominent, thickest and largest of all. Tap root becomes gradually narrow towards the tip. Secondary and tertiary are respectively the branches of first and second order . They are formed in acropetal succession (youngest towards growing point and oldest towards the base of the parent root) . In the orientation, the tap root is vertical, secondary roots are horizontal or oblique while the tertiary roots are the ultimate root branches . They bear root hairs for absorption.

   Tap root system is of two types– deep feeder and surface feeder. Deep feeder tap root system has an elongated tap root which penetrates the deeper layers of the soil . It is also called racemose tap root system . It is mostly met in trees.In surface feeders the tap root does not elongate very much. The secondary roots spread to a greater extent, mostly horizonal near the soil surface. Such a system is also named as cymose tap root system .

2. **Adventitious root system:** Roots which are produced from any other part of plant except the radicle are called adventitious roots. Various types of adventitious roots differ in shape and functions. They may appear from base of the stem replacing the primary root or in addition may arise from nodes or internodes of stem. They usually appear in groups and are clustered. The adventitious roots together with its branches constitute the adventitious root system e.g. grasses, mangrove trees, banyan tree, sugarcane etc. Adventitious roots are mostly surface feeder.

Modifications of roots

Modifications are the morphological changes (changes in shape, form of structure) in an organ to perform certain special functions other than or in addition to the normal functions. To perform secondary special functions, the roots get modified. Some of the modifications are as under:

1. **Tap Root Modifications**

Normal tap roots may undergo modifications in order to perform additional functions like storage of food and water, respiration, perennation and vegetative propagation etc.

a. Storage or fleshy tap roots: *The tap root becomes swollen and fleshy with the stored food. The secondary roots remain thin. Hypocotyl (embryonic region between cotyledons and radicle) may also join the tap root in storing food. Stem is reduced and discoid in the beginning and bears radical leaves. Depending upon the shape, the fleshy tap roots are of the following types.*

I. **Conical:** Here the fleshy tap root resembles a cone, i.e. the thickest towards base and gradually tapering towards the apex. Many thread– like secondary roots are found throughout the length of conical fleshy roots. e.g. carrot *(Daucus carota*).

II. **Fusiform:** The root is spindle-shaped. It is almost uniformly thick except at the base and the apex where it tapers. e.g. Some varieties of *Raphanus sativus* (radish). It also bears a reduced discoid stem with radical leaves. The basal part of the root is derived from the hypocotyl.

III. **Napiform**: This type of fleshy root is thickest at the base and takes the spherical shape. Towards lower side it suddenly thins out. In turnip food is stored in upper swollen part which is devoid of secondary roots hence develops from hypocotyl. Tap root shows its presence towards the narrow, thin apical side which bears secondary roots, E.g. Turnip (*Brassica rapa*) vern. shalgm, beet (*Beta vulgaris*) vern. chukandar.

IV. **Tuberous roots:** These are thickened tap roots which do not assume any definite form. e.g. *Mirabilis jalapa* (4 o' clock), *Trichosanthes* (vern. Parwal), *Echinocystis lobata*. The tuberous roots in *Echinocystis lobata* is lobed and weigh as much as 22 kg.

b. **Nodulated (Tuberculate) Roots:** The secondary, tertiary or sometimes primary roots in sub–family Papilionaceae of family Leguminosae e.g. Gram (*Cicer arietinum*), Groundnut (*Arachis hypogea*) Barseem (*Trifolium alexandrianum*) and Pea (*Pisum sativum*) bear small nodule- like swellings. These contain nitrogen fixing bacteria (*Rhizobium leguminosarum*) which convert free atmospheric nitrogen into organic compounds of nitrogen through the process of nitrogen fixation. Bacteria and leguminous plant show the phenomenon of mutual benefit exhibiting symbiosis. These plants increase the fertility of soil by adding nitrates after the death of these roots.

c. **Respiratory or breathing roots:** They are present in some plants, e.g. *Sonneratia*, *Avicennia* and *Heritiera* etc. of mangrove vegetation, growing in the saline swamps, marshes, lagoons, along the sea shores.

The primary root bears horizontally growing cable roots which in turn bears vertically growing negatively geotropic branches called pneumatophores. The pneumatophores have aerial and submerged parts. The aerial distal part is covered on the outside by a corky layer. The latter is interrupted here and there by numerous lenticels (pores) which help in the exchange of gases. The proximal submerged part bears many short absorbing roots.

2. Adventitious Root Modifications

Adventitious roots do not appear from radicle of embryo, instead they arise from other parts of plant. They may appear from parts like stem or leaves and are normally fibrous and surface feeders but some may be adapted for special functions like storage, support, assimilation etc. Some of the important types are as under:

a) **Fibrous roots:** They may appear due to repeated branching of radicle. These roots are thin almost of equal length, thread- like and arise from the base of erect stem or nodes of horizontal stem. As they do not go deep into the soil, they behave as surface feeder. They appear in clusters and perform the functions of fixation and absorption. e.g. wheat (*Triticum*), grasses and maize .

b) **Fleshy adventitious roots:** As in tap roots, sometimes adventitious roots also become swollen and thick due to storage of reserve food. They can be further classified into following types:

I. **Tuberous (Single root tubers):** The swollen roots do not assume a definite shape. They occur singly. e.g. Sweet potato (*Ipomoea batatas* vern. Shaker kandi)

II. **Fasciculated roots:** The swollen roots or root tubers occur in clusters. In *Dahlia* they lie at the base of the stem while in *Asparagus* the fasciculated fleshy roots occur at intervals on the normal roots.

III. **Palmate roots:** The fleshy roots are thickened like the palm of human hand. Similarly they possess finger- like outgrowths. e.g. *Orchis*.

IV. **Nodulose roots:** In these roots, swellings occur only near the tips. e.g. *Curcuma amada* (Mango ginger) and *Curcuma domestica* (Turmeric). They are known as nodulose roots.

V. **Moniliform or beaded roots:** The roots are swollen at regular intervals like beads of a necklace. e.g. *Basella rubra* (Indian Spinach vern. Kulfa), *Momordica*, some grasses.

VI. **Buttress roots:** Such roots appear from the basal parts of main stem and spread in different directions in the soil. They are vertically elongated and horizontally pressed. They are irregular, thick and broad like planks of wood. e.g. *Ficus, Bombax, Terminalia* etc.

c) **Roots meant for providing additional support to the plant**– These are of three types.

I. **Prop roots:** These are large pillar–like roots, which appear from large horizontal branches in trees like banyan (*Ficus benghalensis*). These adventitious roots grow downwards, which may finally enter into the soil. These roots are provided with root caps. These hanging roots change their colour from brown to red after absorbing water from atmosphere. As they look like pillars, hence called as pillar roots. Sometimes these pillar roots and main stem are of same thickness. They support or prop up the horizontal branches like pillars. Even if the main trunk die, the prop roots fully replace it. With the help of prop roots, banyan tree can spread over a large area and becomes almost immortal.

II. **Slit roots (Brace roots):** They are short but thick supporting roots which develop obliquely from the basal nodes of the stem. In sugarcane, maize, *Pennisetum* and *Sorghum* the slit roots grow in whorls. After penetrating the soil, they provide support to the long, narrow jointed and unbranched stems (culms) like the ropes of pole or TV antenna. In screwpine or *Pandanus* the slit roots develop only from the lower surface of the oblique stem to provide support. They have much folded multiple root caps.

III. **Clinging or climbing roots:** Certain weak stemmed climbers bear adventitious roots that aid the plant in climbing. Examples are found in *Tinospora, Pothos* (money plant), *Piper betle* (betel) and *Hedera helix* (ivy). The adventitious roots may grow from nodes (*Pothos*) or internodes (*Hedera helix*). The roots either enter into crevices or fissures (crack) of the support (*Pothos*) or stick firmly to the support by secreting a cementing gummy substance (*Ficus pumila*) in *Piper betle* the clinimg adventitious roots arise from the nodes. They develop flattened plate- like adhesive discs which secrete a sticky fluid. This cementing fluid help the roots stick firmly to support.

d. Roots meant for vital functions: They are of following types:

I. **Photosynthetic or Assimilatory roots:** Roots are usually non- green. In some plants such as *Tinospora*, *Taeniophyllum* and *Trapa*, the adventitious roots are exposed to light, become green and carry on photosynthesis. Such roots are called as photosynthetic or assimilatory roots . In *Tinospora* (Vern. Gilo), the photosynthetic roots arise as green hanging threads from the nodes of the stem during the rainy season. They however, shrivel during the drought. *Taeniophyllum* (an orchid) is a leafless epiphyte. The aerial adventitious roots are flattened ribbon- like, turn green and assimilate CO_2 in the presence of sunlight. *Trapa* (vern. Sanghara) is a water plant (hydrophyte). Its finely branched submergrd roots are green and carry on photosynthesis.

II. **Parasitic or Haustorial roots:** They are found in parasitic plants like *Cuscuta* (dodder, vern. Amar bel, Akash bel) *Viscum* (mistletoe) *Loranthus* etc. These adventitious roots develop from the stem of the parasite and penetrate into the host where they establish contact with its vascular tissue. As a result, the parasite is able to obtain food, water and minerals from the host. Hence, these are called parasitic or haustorial roots. *Cuscuta* has non–green stem and bears scale leaves. It grows as a total parasite on hosts such as *Zizyphus*, *Duranta Acacia* and *Clerodendron* etc. and obtains both water and food from the host. *Viscum* on the other hand is a partial parasite and bears green leaves. It sends its roots into the host for absorption of water and mineral salts only.

III. **Epiphytic roots (Hygroscopic roots):** The roots occur in epiphytes (plants living on the surface of other plants for shelter and space only; hence are also called as space parasites). Epiphytes bear three types of roots– clinging (for fixation), absorbing (for absorbing mineral salts and moisture from dust collected on bark) and hygroscopic or epiphytic. The epiphytic roots are thick, irregular and hang down in the air. They do not have root caps and root hair. Instead they possess a covering of dead spongy tissue known as velamen. With the help of velamen, the epiphytic roots are able to absorb water from moist atmosphere, dew and rain, e.g. *Vanda*, *Dendrobium*.

IV. **Contractile roots:** The roots can shrink 60-70% of the original length. This brings an underground organ to its proper depth in the soil, e.g. corm of *Crocus* and *Freesia*.

V. **Floating roots:** They occur in *Jussiaea* (=*Ludwigia*). Here a number of adventitious roots arise from each node. Some of them store air, become inflated, project out of water, make the plant light and function as the root floats. The root floats help the plant in floating on the surface of water. They also help in gaseous exchange (hence also called as respirarory roots).

VI. **Leaf roots:** In the floating plants of *Salvinia*, one leaf of each node is modified into roots for balancing the plant in water.

VII. **Root thorns:** In *Pothos armatus* and *Acanthorhiza*, some of the adventitious roots are replaced by hard, thick and pointed thorns. They are called root thorns (thorn roots). In *Iriartea exorhiza* the roots develop hard and spiny outgrowths known as root spines.

VIII. **Reproductive roots:** These adventitious roots are generally fleshy and develop adventitious buds. The adventitious buds can grow into new plants under favourable conditions. Such roots are called reproductive roots, e.g. Sweet potato (vern. Shaker kandi), *Dahlia*.

Functions of the Root

Roots perform two kinds of functions- primary(main) and secondary(accessory). The primary functions are the concern of all the roots and are structurally adapted to perform them. The secondary functions are specialized ones and are performed only by those roots which are modified accordingly.

Primary or main functions

1. **Anchorage:** Roots take part in fixation of the plant and supporting the aerial shoot system.
2. **Absorption of Water:** Roots absorb water from soil.
3. **Absortion of Minerals:** Roots absorb mineral salts from soil.
4. **Prevention of Soil Erosion:** Roots hold the soil particles firmly to prevent soil erosion.
5. **Transport:** They take part in transport of absorbed water and minerals to shoot system.

Rootless plants: Many plants growing in aquatic habitats do not possess roots because there is little requirement for absorption of water and mineral salts e.g. *Wolffia*, *Utricularia*, *Myriophyllum*, *Ceratophyllum*. In other aquatic plants, roots develop only for branching (e.g. *Lemna*, *Pistia*) and fixation (e.g. *Hydrilla*).

Secondary or Accessory Functions

1. **Storage:** It occurs in fleshy roots. Examples of fleshy tap roots are: (i) conical, e.g. Carrot (ii) fusiform, e.g. Radish (iii) napiform, e.g. Beet, Turnip and (iv) tuberous, (e.g. *Mirabilis*)
2. Depending upon their shape and grouping, adventitious fleshy roots are of six types: (a) tuberous (root tubers), e.g. Sweet potato (b) fasciculated, e.g. *Asparagus*, *Dahlia* (c) palmate, e.g. *Orchis* (d) nodulose e.g. *Curcuma* (e) moniliform, e.g. *Momordica* (f) annulated, e.g, Ipecac.
3. **Extra or Mechanical Support:** It is provided by several types of roots: (1)buttress roots (plank roots) e.g. *Bombax* (ii) prop roots, e.g. Banyan, *Rhizophora* (iii) slit roots, e.g., Maize, Sugarcane, *Pandanus* (iv) haptera, e.g., *Podostemum*.
4. **Climbing:** Roots help some of the weak stemmed plants to cling and hence climb up a support, e.g., Ivy, Betel, Money plant.
5. **Perennation:** In many biennial and perennial plants e.g. *Trichosanthes*.
6. **Nitrogen fixation:** Nodulated roots of Pea, Bean. Gram, Methi etc.
7. **Aeration:** Prop roots, knee roots and pneumatophores of mangrove plants, e.g. *Rhizophora*, *Hertiera*.
8. **Reproduction:** By bearing adventitious buds on both tap roots (e.g., *Dalbergia*)and adventitious roots(e.g., Sweet potato)
9. **Hygroscopic roots:** the roots absorb water from air, e.g. epiphytic roots, young prop root of Banyan.
10. **Lavelling:** Bringing the under ground stem to their proper level in the soil as in contractile roots, e.g., *Crocuss*, *Canna*.
11. **Floating:** By storing air (e.g., *Jussiaea*=Ludwigia) some of the roots functions as floats.
12. **Balancing:** Free floating plants usually possess a cluster of adventitious roots from their nodes and bases to help in balancing the plants over the water surface, e.g., *Lemna*, *Pistia*, *Eichhornia*.
13. **Photosynthesis:** As in *Trapa*, *Taeniophyllum*, *Tinospora*, *Podostemum*.

14. **Oxidation:** The roots of some amphibious plants release oxygen and oxidise the surrounding environment, e.g., Rice.
15. **Haustoria:** They occur in some parasitic plants for absorption of food from the host, e.g. *Cuscuta, Mistletoe*.
16. **Mycorrhiza:** The roots of several plants are associated with fungi to form mycorrhiza. This helps the plant in absorption of phosphorus and nitrogen from organic sources and protects the plants from attack of pathogenic fungi.

MORPHOLOGY OF STEM

Stem is usually an above-ground, aerial, erect, ascending axis of the plant body which develops from the plumule and epicotyl of the embryo of a germinating seed. There are also several plants in which the stem is weak and it either creeps on the ground or twines or climbs over a support.

It is distinguished into nodes and internodes. It bears the similar axis, the branches, and the dissimilar appendages, the leaves. The main stem and its branches grow by terminal (apical) buds. The nodes bear the leaves, each having an axillary bud. The branches develop from buds and are exogenous in origin. The stem along with its leafy branches constitute the shoot system of the plant.

Buds

A bud is a condensed immature or embryonic shoot having a growing point surrounded by closely placed immature leaves. The largest bud is that of cabbage. According to their nature, buds can be (i) vegetative (that form only leafy shoots) (ii) floral (reproductive buds that form flowers) and (iii) mixed (forming both vegetative and floral branches). According to their position, buds can be terminal or lateral. The lateral buds are of four types- axillary (developing in the axils of leaves), accessory (additional buds occurring either on the side or above the axillary bud, hence of two types, collateral and superposed), extra-axillary (developing on the node but outside the leaf base) and adventitious (formed from places other than nodes). Adventitious buds can be foliar (on leaves, e.g. *Bryophyllum, Begonia*), radical (on roots e.g. *Dalbergia*, Sweet Potato) and cauline on the stem at places (e.g. Jack Fruit). Buds may become active as soon as they are formed or remain dormant (e.g. winter buds) for short or long periods. The active buds are usually naked (without covering scales) while the dormant buds are commonly covered (closed buds) by protective scales having hair, waxy coating or resin e.g. *Ficus, Calotropis, Zizyphus*.

Fleshy buds which take part in vegetative reproduction are called bulbils. Bulbils may be axillary (e.g. Lily, *Dioscorea*), on the leaf (e.g. *Cardamine*), in place of flowers (e.g. *Agave*, *Onion*) or base of the swollen roots as in *Oxalis*. Fleshy buds functioning in perennation in aquatic plants are called turions (e.g. *Potamogeton, Utricularia*). Buds are also modified into tendrils (e.g. *Passiflora, Cucurbita, Antigonon*) and thorns (e.g. *Duranta*).

Characteristic of Stem

1. Stem develops from the plumule and epicotyl of the embryo.
2. It is generally an aerial and ascending part of the plant axis.
3. It bears a terminal bud for growth in length.
4. It is differentiated into nodes and internodes.
5. The stem and its branches bear leaves at the nodes.
6. The young stem is green and is thus photosynthetic.
7. Hair, if present are generally multicellular.
8. Stem branches and leaves arise exogenously.
9. When the plant is mature, the stem branches bear flowers and fruits.
10. They are negatively geotropic and positively phototropic.

Branching of Stem

In some cases, stem is unbranched and called as caudex or columnar, e.g. *Cocos nucifera, Phoenix, Saccharum officinarum* (sugarcane). Branching of stem is of two types:

I. **Dichotomous:** Here growing point gets divided into two in the region of branching. e.g. *Dictyota, Marchantia* and *Asclepias syriaca*.

II. **Lateral:** In such cases branches appear exogenously from the lateral vegetative buds. Lateral branching can be further classified into two kinds, i.e. Racemose and cymose.

a. **Racemose branching**

In racemose or monopodial branching, the axis of plant grows indefinitely due to the continued activity of terminal or apical bud. The lateral branches appear in acropetal succession, i.e. older towards the base and younger towards the apex. The lateral branches do not compete with the growth of main stem. e.g. *Pinus, Eucalyptus, Polyalthia* etc.

b. **Cymose branching**

In this type of branching, the terminal or apical bud after forming a small portion of axis, either stops its activity or gets modified into flower, tendril, thorn etc. The further growth of the axis is continued by one or more lateral axillary buds that become active. The cymose or definite branching is of following three types:

i. **Uniparous or monochasial cymose branching**
In this type of branching, when the terminal or apical bud stops its activity, further growth takes place by a single axillary branch. Soon buds also stops its growth and process is repeated. The axis of the plant thus formed is false because it is constituted due to the fusion of basal part of successive lateral branches and called as sympodial axis. Two distinct sub-types can be identified, i.e. uniparous scorpioid and uniparous helicoid types.

In uniparous scorpioid types, successive lateral branches appear on alternate sides. e.g. *Vitis vinifera* (grape vine) and *Crataegus crenulata* (howthorn). Axis in such cases is sympodial and bears leaves on alternate sides (right or left) on successive nodes. In grape vine, leaf opposed tendrils represent the modified tip of branches, the base of which fused to form the straightened axis. In uniparous helicoid type, successive branches appear on one side only. e.g. *Saraca indica* (Ashoka tree). Axis in this case is also sympodial which bears leaves on one side only.

ii. **Biparous or dichasial cymose branching**
In biparous type of cymose branching after the stoppage of growth of terminal bud, growth of plant axis is continued by the activity of two lateral branches. The process is repeated. The axis is said to be multipodial. e.g. *Sterllaria, Carissa* (Karonda), *Viscum* (*Mistletoe*), *Mirabilis jalapa* (4 O' clock), *Dianthus* (Pink).

iii. **Multiparous or polychasial cymose branching**

After the stoppage of growth by terminal or apical bud, growth of plant axis is continued by the activity of more than two lateral buds. e.g. *Euphorbia helioscopia, E. tirucalli*. The axis in this case is multipodial.

Forms of Stems

Predominantly the stems are aerial or epiterranean. They grow above the surface of the soil. Stems of some plants grow in the soil. Such stems are called underground or subterranean.

In some plants, the aerial stems trail or creep on the ground. They are called sub-aerial or sub-epiterranean stems.

Aerial Stems (Epiterranean Stems)

They are of three types – reduced, erect and weak.

(A) Reduced Stems: The stem is reduced to a small disc. Nodes and internodes are not distinguishable. Such a green discoid stem occurs in the vegetative phase above the base of root in radish, carrot, turnip, etc. Leaves are crowded together on these stems. They are called radical leaves. In some aquatic plants (*Lemna, Spirodela, Wolffia*) the reduced discoid stem is green and flattened to float on the surface of water. It does not bear leaves. A reduced nongreen stem is also found in underground structures called bulbs. e.g. onion.

(B) Erect Stems: They are the commonest type of aerial stems. The stems are sufficiently strong to remain erect or upright without any external support. e.g. Maize, Wheat, Mango. Erect stems with swollen nodes or jointed stems are called culms (e.g. as in *Bamboo*). Unbranched erect stem is otherwise called caudex or columnar while the branched ones are either excurrent or deliquescent.

(C) Weak Stems: The stems are thin, soft and weak. They cannot stand erect and therefore require a support. Weak stems can be upright or prostrate.

1. **Upright weak Stems:** They are of two kinds, twiners and climbers.

(i) **Twiners:** The stem is long, flexible and sensitive. It can coil around an upright support like a rope (e.g. as in *Lablab, Ipomoea, Convolvulus*). Depending upon the direction of coiling, twiners can be indifferent, sinistrorse (anticlockwise, upper coil disappears at observer's right. e.g. *Convolvulus* and dextrorse (clockwise, upper coil disappears at observer's left. e.g. *Lablab*).

(ii) **Climbers:** The stem is weak and flexible but is unable to coil around an upright support by itself. It requires the help of certain clasping or clinging structures. Accordingly, climbers are of four types:

(a) **Root climbers**: The stem clings to the support by adventitious roots, e.g. Ivy, Betel, *Tecoma*

(b) **Tendril climbers:** Tendrils are green thread- like sensitive structures which can coil around a support and help the weak stemmed shoots to climb up. Tendrils may be modified stems (e.g. *Passiflora*), floral buds (e.g. *Antigonon*), leaf (*Lathyrus aphaca*) or leaf part (e.g. *Gloriosa*, Pea, *Clematis*, Smilax)

(c) **Scramblers** (Ramblers): The stems are able to rise up a support by clinging to it with the help of curved thorns (e.g. *Bougainvillea*), floral stalk hooks (e.g. *Artabotrys*), leaflet hooks (*Doxantha unguis-Cati*), spines (e.g. Climbing *Asparagus*) or pickles (e.g. climbing Rose)

(d) **Lianas:** (=Lianes)-They are woody twiners or climbers, e.g. *Phanera* (=*Bauhinia*) *Vahlii*.

2. Prostrate or Sub-aerial weak Stems: The weak stem take the support of ground for spreading and proper exposure of the leaves and reproductive organs. They are of two broad categories- trailers and creepers. The creepers root at intervals while trailers do not do so. Breaking of the different rooted parts help in vegetative reproduction in creepers. Creepers are of three kinds- runners, stolons and offsets.

(a) Trailers (=stragglers): The shoots trail or spread horizontally along the ground without rooting at intervals. e.g. *Convolvulus, microphyllus, Euphorbia prostrata, Tribulus*. Trailers are of two types- **procumbent** (branches flat on the ground. e.g. *Tribulus, Convolvulus microphyllus= Evolvolus*) and **decumbent** (some branches partially vertical, e.g. *Portulaca, Tridax*).

(b) Runners: They are special, narrow, green, above ground horizontal or prostrate branches which develop at the base of erect shoots called crowns. A number of runners arise from one erect shoot. They spread in different directions and ultimately bear new crowns and tufts of adventitious roots. The processes is repeated. Each runner has generally one or more nodes. The nodes bear scale leaves and axillary buds. The latter can also grow to form new aerial shoots or crown e.g. Lawn grass (*Cynodon dactylon*), Centella (=*Hydrocotyle* Vern. Brahmi booti), Oxalis. In Mint, the horizontal branches may be green and runner-like or underground and sucker-like.

(c) Stolons: They are elongated, horizontal or arched runners which can cross over small obstacles, e.g. Jasmine, Wild Strawberry. Each stolon has one or more nodes possessing scale leaves and axillary buds. The term stolon is sometimes used for underground runner, where the tip unlike sucker, does not come above ground e.g. *Colocasia*.

(d) Offsets: They are one internode long small runners which are found in rosette plants at the ground or water level, e.g. Pistia (water Lettuce), *Eichhornia* (Water Hyacinth).

Underground stems (Underground Stem Modifications)

The underground or subterranean stems lie below the surface of the soil. They are non-green, store food and take part in perennation. Underground stems send up aerial shoots or leaves at intervals during the favourable seasons. Underground stems can be differentiated from roots by (i) Absence of root cap (ii) Absence of root hair (iii) Presence of terminal bud (iv) Presence of nodes and internodes (v) Occurrence of foliage or scale leaves on the nodes (vi) Presence of axillary buds on the nodes (vii) Exogenous branching (viii) Stem-like internal structure. Underground stems are of the following five types:

1. **Sucker:** It is a special non-green slender stem branch, which arises from the underground base of an erect shoot or crown. It grows horizontally in the soil and ultimately comes out to form a new aerial shoot or crown. The process is repeated. Each sucker has one or more nodes with scale leaves and axillary buds. The latter can also sprout to form new crowns, e.g. *Chrysanthemum.* Mint has sucker- like or runner-like lateral branches.

2. **Rhizome:** Rhizome or rootstock is a dorsiventral, horizontal stem growing beneath the surface of soil. Though erroneously known as rootstock, rhizomes are strictly stem in the sense that they bear nodes and internodes. They bear scale leaves, axillary buds and often bear roots at their nodes. Rhizomes are perennial structures. During favourable season, some of their buds develop into leafy shoots, while others form new subterranean shoots. Rhizomes produce adventitious roots in profusion. Its direction is usually horizontal, but in some cases it grows in vertical direction (root stock) or obliquely placed and unbranched. e.g. *Musa paradisiaca* (Banana) and *Dryopteris* (Fern).

   Rhizomes are usually fleshy due to storage of food. The rhizome which is placed horizontally and usually branched is called straggling rhizome. The branching of rhizome may be racemose constituting monopodial axis rhizome. e.g. *Saccharum aurndinaceum*, lotus. Branching is cymose giving the appearance of sympodial axis rhizome. e.g. *Zingiber officinale* (ginger) and *Curcuma longa* (turmeric) and *Canna indica*.

3. **Corm:** It is vertically growing, thick, stout, fleshy spherical or sub-spherical base of an underground stem axis that stores reserve food material. Frequently, the corms are broader than long. Corms are found in *Colocasia* (*taro*, vern. Kachalu), *Amorphophallus* (elephants foot, vern. Zimikand), *Crocus* (Saffron, vern. Kesar), *Gladiolus*, etc. The corms are also distinguished into nodes and internodes. The nodes appear in the form of rings. They bear thin membranous scaly leaf bases. The nodes also bear axillary buds. A large number of adventitious roots are also borne at the base of the corm.

   The corms develop aerial shoots from the apical or axillary buds during the favourable periods. The aerial shoots bear normal green assimilatory leaves. The basal parts of these aerial shoots become thick and fleshy due to the storage of food material. They form new corms. Thus the new corms may develop at the top of the old ones (*Gladiolus, Crocus*) or may be lateral in position (*Colocasia*). The old corms generally shrivel due to the utilization of the stored food in forming the new aerial shoots.

4. **Bulb:** Bulb may be regarded as a short underground stem with fleshy leaf base called scales. Stem is very much reduced and become disc- like. The discoid stem is convex or conical in shape and bears highly compressed internodes. These node bear fleshy scales. On the upper side, disc bears terminal bud surrounded by number of leaves. The axillary buds are present between the axils of leaves. The adventitious roots are borne on the lower side of the disc. The bulbs are of two types:

   (a) Tunicated (b) Scaly

   (a) Tunicated: In tunicated bulb, the scale leaves overlap one another with a dry scale called tunic on the outer side. Bulb is called simple tunicated or layered when the scale leaves are arranged in a concentric manner and form a series of rings. Axillary buds are borne in the axils of fleshy scales. Such bulbs are surrounded by a common sheath of membranous structure on outer side. e.g. *Allium cepa* (Onion), *Narcissus* and *Tulipa* (Tulip). Compound tunicated bulbs in *Allium sativum* (garlic) buds become fleshy. They bear their individual tunics. Such fleshy buds are called bulblets or cloves. These concentric rings of tunicated bulblets are in turn surrounded by overlapping tunics. That is why such type of bulbs are called as compound tunicated bulbs.

   (b) Scaly or Imbricate: In such cases, scale leaves are not concentric. Scale leaves are narrow, small and separated. They are loosely arranged and overlap each other only at their margins. They lack enveloping tunic. e.g. *Lilium bulbifera* (Lily).

5. **Tuber (Stem Tuber):** It is an oval or spherical underground swollen stem structure which does not bear adventitious roots, e.g. Potato (*Solanum tuberosum*), Jerusalem artichoke (*Helianthus tuberosus*). Stem tubers are covered over by a corky skin having lenticels for aeration. Tubers arise at the tips of special narrow underground branches (suckers or stolons). Each tuber possesses number of spirally arranged depressions called eyes which are crowded towards the apical or rose end. The stolen end of the tuber is called heel end. Each eye represents a node. It has a scale leaf in the form of a ridge. The depression contains buds. A piece of stem tuber having an eye can form a new plant. Food reserve is starch in potato and insulin in artichoke. A piece of tuber having at least one eye is used for vegetative propagation.

   Tubers of potato can be recognized to be a stem structure due to

   (a) presence of apical bud on the side opposite the point of attachment;

   (b) Differentiation into nodes and internodes;

   (c) Each eye represents a node. It has a scale leaf in the form of a ridge. The depression contain buds.

SPECIAL MODIFICATION OF STEMS

Stem can be modified to perform different functions. Stem modification can be recognized by their (a) axillary position (b) exogenous origin (c) occurrence of occasional branching (d) differentiation of nodes (e) formation of flowers (f) presence of leaves or buds and (g) internal structure. The various stem modifications are as follows:

1. **Stem tendrils:** The weak stems climb up with the help of thread- like greenish, sensitive structures called as tendrils. They are slender and spirally coiled (spring- like structures). A tendril may be a modification of stem, branch, a leaf or part of leaf. Some stem tendrils are:

(a) **Axillary branch tendrils:** They are found in *Passiflora*. Their axillary position, branched structure and presence of scale leaves and buds on them confirm their stem structure.

(b) **Extra-axillary branch tendrils:** They are found in cucurbits. e.g. Luffa (vern. Ghia tori), *Cucurbita* (vern. Kadooo), Lagenaria (bottle gourd, vern. Lauki) etc. The exact morphological nature of the tendrils is disputable.

(c) **Sympodial axis tendrils:** They are found in grape vine. In Grape vine (*Vitis vinifera*), the main stem is sympodial due to scorpioid type of uniparous cymose branching. The terminal buds of the successive branches which are pushed to one side develop into tendrils.

(d) **Floral bud or Inflorescence tendrils:** They are found in *Antigonon*, *Cardiospermum* (Balloon Vine). In *Antigonon*, the flowers occur in branches in the axils of scale leaves on the floral shoot. The upper floral buds develop into tendrils instead of forming flowers.

2. **Hooks:** The pedicels or floral stalks of *Artabotrys* are modified into stiff curved thorns or hooks for helping in climbing. Hook is formed by peduncle in *Uncaria gambier*.

3. **Stem thorns:** Sometimes the stem branches which appear from axillary buds are deprived of their normal growth and are modified into sharp pointed structures called thorns. Thorns are deep seated structures with vascular connections. Prickels are superficial outgrowths of stem or leaves which do not posses a vascular cylinder. They can be easily pulled off. Bristles are stiff hairs which become thickened due to deposition of silica or calcium carbonate. Spines are usually modified leaves or part of leaves.

   Thorns not only reduce transpiration but also check browsing by animals. Axillary stem thorns occur in *Citrus*, *Bougainvillea*, *Duranta*, *Pomegranate*, *Alhagi* etc. In *Bougainvillea*, the thorns are curved. They help the plant in climbing. In *Duranta*, the stem thorns bear small foliage leaves. In *Alhagi*, they posses flowers. Thorns are terminal and branched in *Carissa*.

4. **Thalamus or Torus:** Flower is a specialized reproductive shoot which possesses a highly condensed axis called thalamus or torus. It forms a broadened tip of pedical or floral stalk. Nodes and internodes are not distinct. Thalamus bears four types of floral organs (sepals, petals, stamens and carpels), each arising from their own nodes. In certain cases, the thalamus nodes become clear due to elongation of internodes between sepals and petals (anthaophore, e.g. *Silene*), petals and stamens (androphore, e.g. *Passiflora*) or stamens and carpels (gynophore, e.g. *Cleome*).

5. **Phylloclade:** It is a green, flattened or cylindrical stem which takes the form and function of leaf. They contain chlorophyll and are responsible for carrying on photosynthesis. It bears succession of nodes and internodes at long or short intervals. Phylloclades are found in xerophytic plants where the leaves either grow feebly or fall off early or modified into spines. e.g. *Opuntia, Muehlenbeckia* (Cocoloba), *Epiphyllum, Euphorbia royleana* etc. In *Opuntia* (vern. Chittarthor), the stem is green and leaf like, it is flattened, fleshy, thick, joined structure which appears in the axile of caducous leaf on node. This phylloclade shows raised areas called areoles. On areoles one or two long spines and stiffened fine hair bristles or glochidia are present. The spines are modified leaves of suppressed axillary branch. The stem- like nature of phylloclade can be confirmed by : (a) axillary position (b) by presence of flowers and fruits on it.

6. **Cladodes or cladophylls:** They are green, cylindrical or flattened stem branches of limited growth. They are considered as phylloclades with one or two internodes. They are borne in the axils of scaly or spiny leaves at the nodes or normal stems. They too carry on photosynthesis in the absence of leaves that are modified into scales or spines. Common examples are *Asparagus*, *Ruscus* (butcher’s broom) etc.

   In *Ruscus*, the cladodes are green, leathery, flattened, leaf-like structures, borne singly in the axils of scale leaves. They are borne on ordinary stem branches. About the middle of each cladode is borne a tiny scale leaf which bears a floral bud in its axil- it is an evidence to establish its stem-like structure.
   Asparagus has needle- like cladodes that are cylindrical and one internode long. Stem bears scaly or spiny leaves; the spiny leaves have ordinary stem branches in their axils. The scaly leaves have more than one cladodes in their axils.

Functions of Stem

The stems perform two types of functions, primary and secondary:

A. Primary or main functions

1. It bears and support leaves, flowers and fruits.
2. The various appendages borne on the stem are placed in such a fashion that they are able to carry out their functions most effectively.
3. It conducts the water and minerals from roots to leaves and fruits.
4. Stem bears flowers and fruits in position to facilitate the processes of pollination and fertilization.
5. Every year it adds new cells, tissues and organs which are required for the continued functioning of the plants.

B. Secondary or Accessory functions

1. **Storage of food:** In a large number of plants, the stems store food and water. e.g. *Solanum tuberosum* (Potato), *Colocasia*, ginger etc.
2. **Perennation:** The underground stems help to tide over the unfavourable growing period. e.g. *Zingiber officinale* (ginger, vern. Adrak), *Curcuma domestica* (turmeric) etc.
3. **Vegetative propagation:** In a large number of plants, the stems are used for vegetative multiplication as in case of runners (e.g. Grass), stolons (Strawberry), offsets (*Eichhornia*) and underground stems (e.g. Potato, Ginger etc.)
4. **Photosyntheis:** In some xerophytes, the stem becomes green and modified into leaf-like structures, the cladodes or phylloclades. They help in photsyntheis in the absence of leaves which are reduced to scales or spines. e.g. *Ruscus, Asparagus, Opuntia* etc.
5. **Protection against browsing:** In *Duranta, Citrus, Bougainvillea* etc. the axillary buds are modified into thorns to protect the plants from browsing animals.
6. **As climbers:** The stems may be modified into tendrils, hooks, thorns etc. to climb. e.g. *Passiflora, Bougainvillea* and *Vitis vinifera*.
7. **Receptacle for floral organs:** In a flower, the floral organs are borne on the thalamus. The thalamus is a modified stem which has condensed and overlapping nodes and internodes.

MORPHOLOGY OF LEAF

The leaves are green, flattened, thin, lateral, exogenous appendages borne at the nodes of the stems. They are mostly stalked, of limited growth and bear axillary buds. They are the chief photosynthetic organs of the plant. Collectively they constitute the foliage of the plant. They are always borne in an acropetal manner on the stem or its branches.

Characteristics of Leaf

1. Leaves are dissimilar, lateral outgrowths of the stem.
2. They are borne on the stem at the nodes.
3. They are exogenous in their origin and have a limited growth.
4. They bear axillary buds in their axils.
5. Leaves do not bear any apical bud (of stem and root) or a regular growing point.
6. A leaf is differentiated into three-parts, the leaf base, petiole and lamina.
7. The lamina is traversed by prominent streaks called the veins.

Parts of a Leaf

A leaf consists of three parts- leaf base, petiole and lamina. **Lamina** (=epipodium) or leaf blade is the terminal thin, expanded, green and conspicuous part of the leaf which is specialized to perform photosynthesis. The flattened lamina or leaf blade is supported by veins and veinlets which contain vascular tissues.

Petiole (=mesopodium) is a cylindrical or subcylindrical stalk of the leaf which lifts the lamina above the level of stem so as to provide it with maximum exposure. Leaf having petiole is called petiolate. It is termed sessile if the petiole is absent.

Leaf base (=hypopodium) is the lowermost part of the leaf by which the leaf is joined to the node of the stem. Leaf base is often indistinguishable from the petiole. In many legumes, it is swollen. The swollen leaf base is known as pulvinus. It is responsible for sleep and shock movements of certain leaves. e.g. *Mimosa pudica*. Leaf base may be broadened to enclose the stem. It is called sheathing leaf base. The latter is of two types- amplexicaul (enclosing stem completely as in Grasses, Wheat) and semi-amplexicaul (enclosing the stem partially, e.g. Buttercup). Leaf base often contains two small lateral outgrowth called stipules. A leaf with stipules is called stipulate while the one without stipules is termed as exstipulate. In grasses an outgrowth is present between leaf base and lamina. It is called ligule. The leaf with ligule is called ligulate.

Stipules: They are two small lateral outgrowths of the leaf base which protect the young leaf and its axillary bud in the young state. In some compound leaves, the leaflets bear basal lateral outgrowths named stipules. e.g. Bean, *Clitoria*, *Vicia*. Different types of stipules are

- (i) **Free lateral:** Small, free, green outgrowths, e.g. Shoe-flower (*Hibiscus rosa-sinensis*).
- (ii) **Scaly:** Very small dry membranous stipules, e.g. *Cassia fistula*
- (iii) **Axillary or intrapetiolar:** Stipules are fused from their inner margins to become axillary. e.g. *Gardenia*.
- (iv) **Opposite:** Stipules are fused from their outer margins to become opposite the leaf. e.g. Castor
- (v) **Interpetiolar:** Adjacent stipules of opposite leaves are fused to appear in between the leaves. e.g. *Anthocephalus* (Kadam), Ixora.
- (vi) **Adnate or petiolar:** Stipules fused with petiole, e.g. Rose, Groundnut.
- (vii) **Ochreate:** Stipules fuse to form a sheath or ochrea around the stem, e.g. *Rumex*, *Polygonum*.
- (viii) **Bud scales:** Stipules of young leaves connate to protect bud, e.g. Ficus
- (ix) **Foliaceous:** Large and green, e.g. *Pisum*
- (x) **Stipular spines:** Stipules are transformed spines. e.g. *Acacia*, *Zizyphus*. The two stipular spines of *Zizyphus* are unequal with one straight and second hooked.
- (xi) **Stipular tendrils:** Stipules are modified into tendrils. e.g. *Smilax* for climbing.

Phyllotaxy (=Phyllotaxis)

The arrangement of leaves on a stem or branch is called phyllotaxy. Phyllotaxy can be defined as mode of distribution of leaves on stem. The aim of phyllotaxy is to orient the leaves in such a way that they receive maximum sunlight to perform the function of photosynthesis. Phyllotaxy is of three main types:

1. Alternate or spiral: When there is only one leaf borne at each node, the arrangement is called spiral or alternate or acyclic. e.g. *Hibiscus* (China rose), *Nicotiana* (Tobacco), *Ficus religiosa* (Peepal). Leaves are usually arranged spirally around the stem. The number of vertical rows in which leaves are arranged is called as orthostichies. On the basis of angular divergence i.e. angle subtended between two consecutive leaves, the spiral phyllotaxy is sub-divided into many sub-types.

$$\text{Angular divergence} = \frac{\text{No. of circles}}{\text{Orthostichies}} \text{ of a circle i.e. } 360^{\circ}$$

(i) Distichous or ½ phyllotaxy : Where the angular divergence is ½ of 360º i.e. 180º e.g. *Ravenella*.

(ii) Tristichous or 1/3 phyllotaxy : Where the angular divergence is 1/3 of 360º i.e. 120º e.g. Moss, *Cyperus rotundus*.

(iii) Pentastichous or 2/5 phyllotaxy : Where the angular divergence is 2/5 of 360º i.e. 140º e.g. China rose.

(iv) Octastichous or 3/8 of 360º i.e. 135º e.g. *Carica papaya*.

In these types, if one adds up two preceeding numerator and denominators, a series is formed called Schimper-Brown series.

e.g. $\frac{1}{2}, \frac{1}{3}, \frac{1+1}{2+3} = \frac{3}{5}, \frac{1+2}{3+5} = \frac{3}{8}, \frac{2+3}{5+8}, = \frac{5}{13}$ and so on.

2. Opposite: In opposite phyllotaxy, two leaves appear at each node and lie always opposite to each other. It is further of two types:

(a) Opposite and superposed: When the opposite leaves of two adjacent nodes are in the same direction i.e. two opposite leaves of one node lie exactly below those of the upper node and above those of the lower node in the same plane, the phyllotaxy is called as opposite and superposed. e.g. *Eugenia* (Jamun), *Quisqualis* (Rangoon creeper).

(b) Opposite and decussate: In this type of phyllotaxy, the leaves of successive nodes are placed at right angle to each other and thus the leaves get arranged in four vertical rows e.g. *Calotropis* (Aak), *Ocimum* (Tulsi) and *Zinnia*.

3. **Whorled or Verticillate:** When three or more leaves are present at node, phyllotaxy is known as whorled or verticillate. They are borne in whorl or circle. e.g. *Nerium* (Oleander Vern. Kaner), *Alstonia*, *Galium*.

Venation

The mode of distribution or arrangement of veins in the lamina (leaf-blade) is called venation. Veins and veinlets are skeletal as well as conducting prominences visible on the surface of lamina, especially the under surface in dorsiventral leaves.

The important functions are (i) conduction of water through xylem (ii) Providing channels for translocation of organic nutrients (iii) Conduction of minerals (iv) By their large number, the veins and veinlets provide skeletal support to the lamina, so that it can remain stretched for its optimum functioning (v) Veins and veinlets reduce the effect of wilting.

There are three main types of venation.

1. Reticulate
2. Parallel
3. Furcate

1. Reticulate venation: When the veins are irregularly distributed to form a network, it is known as reticulate venation. It is a characteristic feature of the dicotyledons. Reticulate venation is of following types:

(a) Unicostate reticulate (Pinnate reticulate): A leaf with a single main midrib or costa is called unicostate reticulate. e.g. *Eugenia* (Jamun), *Oleander* (Kaner), *Ficus religiosa* (Peepal), *Hibiscus*.

(b) Multicostate reticulate (Palmate reticulate): When there are two or more costae or principal veins arising from a single point. It is of two types:

(i) Multicostate convergent: Many principal veins curved in a curved manner from the base of blade to is apex. e.g. *Zizyphus* (Beri).

(ii) Multicostate divergent: Principal or main veins are at the base of leaf and then diverge from one another towards the margin of leaf. e.g. *Cucurbita*, *Luffa* and *Carica papaya* (Papita).

2. Parallel venation: When the veins are parallel and do not form a network, such a venation is called parallel. It is of two kinds:

(a) Unicostate parallel (Pinnate parallel): The lamina has a single prominent midrib and from this arise lateral veins which run towards the margin. e.g. Banana, Turmeric.

(b) Multicostate parallel venation (Palmate parallel): In this case several veins run parallel to one another.

It can be classified into two types:

(i) Multicostate convergent – The principal veins appear from the base of lamina and converge at the apex. e.g. *Bambusa* (Bamboo), grasses.

(ii) Multicostate divergent – The main vein appears from the base of lamina towards the margins. e.g. *Borassus flabellifer* (Fan palm).

3. Furcate venation: Such types of venation is present in ferns. In such cases, veins divide dichotomously. The finer branches do not meet to form a reticulum or network.

Exceptions: There are a few exceptions to above mentioned examples. e.g. Monocotyledons like *Dioscorea*, *Smilax* show reticulate venation and *Calophyllum* (Dicotyledon) exhibits parallel venation.

Venation

Reticulate Parallel

Pinnate Palmate Pinnate Palmate

(Pipal, Jamun) (Ginger, Banana)

Convergent Divergent Convergent Divergent

(*Zizyphus*) (*Cucurbita*) (Bamboo, Grass)

Simple and Compound Leaves

Depending upon the incisions of the lamina the leaves are of two kinds – simple and compound.

Simple Leaves

A leaf having single leaf blade is called simple leaf. The margins of the lamina of such leaves may be entire or deeply incised to various depth. The incisions never divide the lamina into distinct leaflets. e.g. *Ficus religiosa, Luffa, Ricinus communis, Cannabis, Tagetes* etc.

Incisions of leaf blade

It is the process of dividing or partitioning of the leaf blade. The degree of incisions varies in different plants. In pinnately veined (unicostate) leaves the incisions proceed from the margin to the mid-rib while in palmately veined (multicostate) leaves, these proceed from the margin to the tip of the petiole. The incisions of the lamina are of following types:

(i) **Pinnatifid:** The incisions are hardly half way from the margin to the midrib. e.g. *Chrysanthemum*.

(ii) **Pinnatipartite:** The incisions are more than half way from the margin to the midrib. e.g. *Launaea*.

(iii) **Pinnatised:** The incisions almost reach the midrib. e.g. *Tagetes*.

(iv) **Palmatifid:** The incisions are hardly half way from the margin to the tip of the petiole. e.g. *Gossypium* (cotton).

(v) **Palmatipartite:** The incisions are more than half way from the margin to the tip of the petiole. e.g. *Ricinus* (castor).

(vi) **Palmatisect:** The incisions almost reach the tip of the petiole. e.g. *Ipomoea palmata* (railway creeper vern. Ishqpecha).

Compound Leaves

A leaf is said to be compound when its lamina is completely divided into distinct segments or leaflets. In such leaves, the leaflets are distinct, free from one another and articulated (joined) to the rachis (midrib) or the tip of the petiole. The leaflets, also known as pinnae, are easily distinguishable by the absence of axillary buds. Broadly speaking, the compound leaves are of two types:

a) **Pinnate compound leaves:** In pinnate compound leaves, the leaflets are borne on an unbranched or branched axis, the rachis (a derivative of mid rib). The latter is an extension of the petiole. The branches of the rachis are called the rachillae, and the leaflets borne on them are called as pinnules. Pinnate compound leaves are of the following types:

(i) Unipinnate: The lamina is divided only once in a pinnate manner. The rachis is unbranched and bears the leaflets (pinnae) on either side of the rachis. The leaflets are borne in opposite or sub-opposite pairs. The leaflets may be sessile or stalked. The unipinnate compound leaves may be paripinnate when the leaflets are even in number (e.g. *Cassia*) or imparipinnate when the leaflets are odd in number (e.g. *Rosa, Murraya*) with a terminal odd leaflet.

(ii) Bipinnate – The lamina is twice pinnate. Here, the rachis bears branches of the first order, the rachillae. The leaflets (Pinnules) are borne on these primary branches (rachillae) e.g. *Acacia, Albizzia* etc.

(iii) Tripinnate – The lamina is thrice pinnate. Here the rachis is branched twice. The leaflets (pinnules) are borne on the branches of the second order. e.g. *Moringa* (vern. Soanjana) and *Melia azedarach* (vern. Dharek) etc.

(iv) Decompound: The lamina is more than thrice pinnate. The rachis is branched more than twice. The pinnules are borne on the branches of the final or ultimate order. e.g. *Daucus carota* (carrot), *Foenuculum* (fennel), *Coriandrum* (coriander) etc.

In decompound leaves, often the lamina is suppressed and rachis alongwith its branches become flattened.

(b) Palmate compound leaves: In a palmate compound leaf, the leaflets are borne terminally on the petiole. The palmate compound leaves are classified on the basis of the number of the leaflets. They are of following types:

(i) **Unifoliate:** A single leaflet is articulated to the tip of the petiole. Such leaves are rare. e.g. *Citrus*. The leaf of *Citrus* looks like a simple leaf, however, its compound nature can be confirmed due to (i) presence of joint between lamina and petiole (ii) by many abnormal leaves, where two leaflets alongwith central one make their presence. So the Citrus is basically trifoliate compound leaf but due to suppression of two lateral trifoliate it has become unifoliate.

(ii) **Bifoliate:** Two leaflets are joined to the petiole. E.g. *Hardwickia, Prinsepia*.

(iii) **Trifoliate:** Three leaflets are articulated at the tip of the petiole. e.g. *Aegle marmelos* (wood-apple vern. Ball), *Oxalis, Medicago* (methi), *Trifolium* etc.

(iv) **Quadrifoliate:** Four leaflets are articulated at the tip of the petiole. Such leaves are rare. E.g. *Paris quadrifolia* and *Marsilea*.

(v) **Multifoliate:** Four or more leaflets are articulated to the tip of the petiole. The leaflets spread out like the fingers of a palm. e.g. *Salmalia* (=*Bombax*) *malabarica* (Silk-cotton tree vern. Simbal) etc.

Modifications of Leaves

The leaf or part of leaf is occasionally modified into other structure. They can perform special functions other than photosynthesis. Prominent examples are:

1. **Leaf tendrils:** Tendrils are thread–like green structures which are sensitive to touch and are capable of cooling around the support. They can be differentiated from stem terndrils by absence of scale leaves over them and being unbranched. Following are the examples of leaf tendrils:

a) **Whole leaf tendrils:** In *Lathyrus aphaca* (wild pea), the entire leaf is modified into a tendrils. The functions of the leaves are taken up by large foliaceous (leaf like) stipules.

b) **Leaflet tendrils:** In *Lathyrus odoratus* and *Pisum sativum*, the upper leaflets of the pinnate compound leaf are modified into tendrils. The stipules in these plants are also foliaceous.

c) **Petiolar tendril:** The petioles of Garden Nasturtium (*Tropaeolum majus*) and *Nepenthes* are elongated, sensitive and capable of coiling around the support like the tendrils.

d) **Stipular tendril:** In *smilax*, the stipules are modified into tendrils.

e) **Leaf tip tendrils:** In *Gloriosa superba*, the leaf tip is modified into a tendril.

2. Leaf spines: In plants like *Barberry*, *Opuntia* leaves are modified into spines. These protect the plant from grazing animals and also reduce the area for transpiration. The leaf nature of spines can be made out by the presence of buds in their axils.

3. Food storage: Food is stored in the leaves of *Allium cepa* (onion). The leaves may also become fleshy or juicy (succulent) due to storage of water, mucilage and food material. e.g. *Aloe* and *Portulaca*.

4. Leaf pitcher: The leaf or lamina is modified to form a large pitcher in *Dischidia, Nepenthes* and *Sarracenia*. In epiphylic *Dischidia*, the whole leaf is changed into an open pitcher for storing rain water. The same is absorbed throughout the year by adventitious roots (nest roots). In *Nepenthes* and *Sarracenia*, the pitchers are meant for catching and digesting insects. The lamina is modified into pitcher. The leaf apex gives rise to a coloured lid for attracting the insect.

In *Nepenthes*, the leaf base is foliaceous while the leaf stalk is tendrillar. The rim of the pitcher has nectariferous glands. The interior of the pitcher is slippery. The base is filled up with a digestive fluid.

5. Phyllodes: In some plants, the petioles (*Acacia moniliforms*, *Acacia auriculiforms*) and/or the rachis (*Parkinsonia aculeala*) become flattened blade- like structures, green in colour. They are called phyllodes. In such plants, the normal leaves develop in the seedling stage and soon fall off. Afterwards, the phyllodes develop and take the function of photosynthesis in the absence of normal leaf blades. The phyllodes are normally oriented vertically to avoid direct sunlight. Phyllodes also help in cutting down the excessive loss of water during transpiration.

6. Leaf hooks: In certain weak-stemmed plants, the leaves are provided with hooks that help the plants to climb up a support. In *Bignonia unguis-cati*, the three terminal leaflets of the compound leaves become stiff, curved, claw-like hooks. The latter cling to the support firmly and help the plant to climb up.

7. Reproductive leaf: Leaves of *Bryophyllum* and *Begonia* bear adventitious buds on them and help in vegetative propagation of plants.

8. Leaf roots: The leaves are modified into roots in *Salvinia* (water fern). Out of three leaves at each node, one forms roots and the other two remain normal.

9. Heterophylly: The occurrence of different kinds or more than one type of leaves on the same plant is called as heterophylly. In *Ranunculus aquatilis* and *Limnophila heterophylla*, submerged leaves differ completely from floating leaves. In *Eucalyptus* and *Sonchus*, the leaves differ in their shape and size which appeared at different developmental periods on the same plant.

10. Coloured leaves: In *Poinsettia* (*Euphorbia pulcherrima* vern. Lal Patti), the leaves borne near the cyathia are brightly coloured to attract insects for pollination.

11. Floral leaves: Floral organs are specialized leaves – sepals, petals, stamens and carpels. Sepals are protective and green, petals are coloured and attractive, stamens are pollen bearing structures or microsporophylls while carpels are ovule bearing megasporophylls.

Technical Descriptive Terms

A large number of technical terms are used to describe variations in insertion, duration, petiole, shape, margin, apex, surface and texture of leaves. Some of the commonly used terms alongwith examples are as follows:

(a) Leaf Insertion

Leaf insertion is of three types:

(i) Radical: Leaves which are borne on a reduced discoid stem and appear to arise in clusters from the top of the root. e.g. turnip, carrot etc.

(ii) Cauline: Leaves borne at the nodes of the stem (or the main stem). e.g. maize, sugarcane etc.

(iii) Ramal: Leaves borne at the nodes of the stem branches. e.g. *Zizyphus, Dalbergia*.

(b) Leaf Duration

(i) Caducous: Leaves fall off soon after the opening of bud. e.g. *Euphorbia royleana*.

(ii) Deciduous: All the leaves of a plant fall off at the end of growing season one by one or simultanesouly leaving the plant leafless. e.g. *Mulberry, Dalbergia* etc.

(iii) Persistent: The leaves do not fall off simultaneously and the plant is never leafless. Plants with persistent leaves are called evergreen. e.g. *Nerium*.

(c) Petiole or Leaf stalk

(i) Petiolate: A leaf having a petiole (*Ficus*)

(ii) Sessile: A leaf without a petiole (*Sonchus*)

(iii) Sub-sessile: A leaf with a short petiole (*Calotropis*)

(iv) Peltate: A leaf with the petiole attached to the centre of the lamina at the back. e.g. garden nasturtium, lotus.

(v) Inflated or spongy: Petiole is bulbous, swollen and store air. e.g. *Eichhornia*.

(vi) Tendrillar: Petiole is long, coiling and highly sensitive. e.g. garden nasturtium, *Clematis*.

(vii) Winged: Petiole is flattened e.g. *Citrus*.

(d) Shape of Lamina

(i) **Acicular:** The lamina is long, narrow, cylindrical, needle- like with a sharp apex. e.g. *Pinus* (vern. Chil).

(ii) **Linear:** Lamina is long, narrow and flat with an almost uniform width. e.g. grasses (*Cynodon dactylon* and *Triticum*), *Vallisneria*.

(iii) **Lanceolate:** The lamina is long, flat and narrowly round and broad at the top and narrower towards the base. e.g. *Calendula*, Lippia.

(iv) **Sagittate:** The lamina is arrow shaped. e.g. *Colocasia*, *Sagittaria*.

(v) **Hastate:** The base of the lamina is produced into two lobes like a sagittate leaf but the two lobes are directed outwards. e.g. *Ipomoea aquatica* (water bindweed).

(vi) **Auriculate:** The sessile lamina is produced into two ear like lobes at the base, one on either side of the stem. e.g. *Sonchus, Calotropis*.

(vii) **Falcate:** The lamina is sickle–shaped. e.g. *Eucalyptus* (*vern. Sefeda*)

(viii) **Lyrate –** The lamina is pinnately lobed. The terminal lobe is largest and round at the tip. e.g. *Raphanus sativus* (radish)

(ix) **Runcinate:** The lamina is pinnately lobed. The terminal lobe is largest and tapering at the apex giving a triangular outline. e.g. *Sonchus*, *Launea*.

(x) **Rhomboidal:** The lamina is broad in the centre but taper gradually at both the ends. e.g. *Solanum nigrum*.

(e) Margin of the lamina

(i) **Entire:** The margin is even and smooth. e.g. *Nerium* (oleander vern. Kaner), *Magnifera indica* (mango).

(ii) **Repand or undulate:** The margin is slowly and gradually wavy or undulating. e.g. *Polyalthia* (vern Ashok tree), *Ficus religiosa* (vern. Peepal).

(iii) **Serrate:** Margin like a saw with teeth directed broad. e.g. Nerium (Oleander, vern. Kaner), *Callistemon* (bottle brush).

(iv) **Oblong:** The lamina is much longer than wide with a blunt apex. e.g. *Musa paradisiaca* (banana).

(v) **Elliptical or oval:** The lamina is about twice as long as borad. It is broadest in the middle but tapering at either end. e.g. *Duranta, Carrisa* (vern. Karonda).

(vi) **Ovate:** The lamina has broad rounded base and sharp or blunt tapering apex. e.g. *Ficus benghalensis, Ocimum, Hibiscus rosa-sinensis* (shoe flower).

(vii) **Obovate:** The lamina is inversely ovate i.e. it has a broader round apex and a tapering base. e.g. *Terminalia*, Jack fruit.

(viii) **Cordate:** The leaves are ovate with a deep notch at the base. The lamina is described as heart shaped. e.g. *Piper betle* (betel leaf), *Tinospora* (vern. Gilo).

(ix) **Orbiculate or rotund:** The lamina is round or circular in outline. e.g – *Nelumbium* (lotus), *Tropaeolum*.

(x) **Obcordate:** The lamina is inversely cordate. e.g. leaflets of *Oxalis, Bauhinia*.

(xi) **Reniform:** The lamina is kidney shaped e.g. *Malva parviflora* (vern Sonchal, *Centella asiatica* vern. Brahmi booti)

(xii) **Oblique:** The lamina is unequally divided by the midrib e.g. *Begonia*.

(xiii) **Spathulate:** Lamina is spathula like i.e. upwards e.g. *Rosa* (rose), *Mentha* (vern Podina).

(xiv) **(xiii)Biserrate:** Margin doubly serrate i.e. each tooth serrated again e.g. elm tree.

(xv) **Runcinate or Retro–Serrate:** Margin serrated with the teeth pointed back wards e.g. Launea.

(xvi) **Dentate:** Margin toothed. Teeth directed outwards at right angles to the margin of the leaf. e.g. water lily.

(xvii) **Bidentate:** Margin toothed and the teeth are again dentate.

(xviii) **Crenate:** Margin marked by rounded teeth or processes with notches in between. e.g. *Bryophyllum* (sprout leaf plant vern. Patharchat), *Malva parviflora* (vern. Sonchal).

(xix) **Ciliate:** Margin bears a fringe of fine hair. e.g. *Ziizyphus jujube* (vern. Beri).

(xx) **Spinous:** Margin is beset with spines. e.g. *Carthamus oxycantha* (vern. Pohli).

(f) Apex of lamina

(i) **Acute:** The apex forms an acute angle. e.g. *Hibiscus rosa-sinensis, Mangifera indica*.

(ii) **Acuminate or caudate:** The apex is drawn gradually into a tapering point or it is tail like. e.g. *Ficus religiosa* (vern. Banyan)

(iii) **Obtuse:** The apex forms an obtuse angle. e.g. *Ficus benghalensis* (vern. Banyan)

(iv) **Cuspidate or spinose:** The apex is in the form of a long rigid sharp point. e.g. *Aloe vera* (vern. Kanwar Gandal).

(v) **Mucronate:** The apex abruptly ends in a short point. e.g. *Vinca* (vern. Sada Bahar)

(vi) **Tendrillar:** Apex forms sensitive, curled appendages called tendril. e.g. *Gloriosa superba* (glory lily).

(vii) **Truncate:** The apex ends abruptly and appears as if cut off at right angles to the midrib. e.g. *Caryota urens* (toddy palm), *Butea monosperma* (vern. Dhak).

(viii) **Cirrhose:** The mucronate-like apex in a fine thread like structure. e.g. *Musa* (Banana)

(ix) **Retuse:** The obtuse or truncate apex has shallow notch. e.g. *Pistia, Oxalis*.

(x) **Emarginate:** The apical groove or notch as broad and deep, e.g. *Bauhinia* (vern. Kachnar).

(g) Surface of the lamina

(i) **Glabrous:** The surface is smooth and dull. e.g. *Eucalyptus* (vern. Safeda), *Ficus bengalensis* (Banyan tree).

(ii) **Glaucous:** The surface is smooth and shining. e.g. *Ficus religiosa* (vern. Peepal)

(iii) **Glutinous:** The surface is covered with sticky exudation. e.g. *Nicotiana tabacum* (tobacco).

(iv) **Waxy:** The surface is covered with a waxy coating or wax grains. e.g. Calotropis (madar, vern. Aak)

(v) **Pubescent or Hairy:** The surface is covered with dense or sparse hairs. e.g. *Helianthus* (sunflower).

(vi) **Pillose:** Surface covered sparsely with long soft and slendar hairs.

(vii) **Hirsute:** Surface covered with coarse and stiff hairs.

(viii) **Tomentose:** Surface densely covered with short wooly hairs forming a mat.

(ix) **Hispid:** Surface beset with rigid or bristly hairs.

(x) **Canescent or Hoary:** Surface densely covered with fine, short, white hairs.

(xi) **Silicate:** Surface rough due to silica grains. e.g. *Zea mays* (maize).

(xii) **Scabrous:** Surface produced into minute rough projections. e.g. *Morus alba* (mulberry, vern. Shehtoot).

(xiii) **Glandular:** Surface covered with glands. e.g. *Lantana, Citrus*.

Functions of leaf

A. Primary functions

1. The most important primary function of leaf is the manufacture of organic food through photosynthesis. The leaves are green because of chlorophyll. Besides chlorophyll, they also have other photosynthetic pigments. The pigments trap light energy and convert it into chemical energy which is used in the synthesis of organic food.
2. The stomata helps in the gaseous exchange necessary for photosynthesis and respiration.
3. The loss of water through the leaves (transpiration) is greatly assisted by stomata. Transpiration is useful in the ascent of sap and keeping the temperature low in summers.
4. The vascular elements in the veins and petiole help in the conduction and transport of water and minerals from the stem to the lamina and organic food from the lamina to the stem.

B. Secondary or special functions

1. Storage of food in leaf bases e.g. Onion.
2. Water is stored in the leaves which are succulent in nature. e.g. *Bryophyllum, Aloe* etc.
3. Protect the plants from grazing animals when modified into spines. e.g. *Opuntia, Barberry*.
4. It reduces the rate of transpiration when changed into phyllode e.g. *Acacia auriculiformis*.
5. They help in climbing the plants having weak stem, when modified into tendrils and hooks.
6. Leaves help the plants in vegetative multiplication. e.g. *Bryophyllum*.
7. Leaves act as balances for floating when modified into roots. e.g. *Salvinia*.
8. The leaves are modified into sepals, petals, stamens and carpels to take part in sexual reproduction.

Importance of Leaf Morphology

1. Leaf morphology is employed in taxonomy for accurate description, identification and classification of plants. For this, the leaves show specific variations in shape, apex, base, margin, phyllotaxy, venation etc.
2. Crop productivity is determined by rate of leaf production, periods for which they are retained on the plants, their orientation to light, shape, area etc.

3. Some plants show developmental heterophylly. In such plants, shape of the leaves indicates the stage of plant maturity, e.g. Cotton, *Eucalyptus*.
4. Any peculiarity of shape, size, colour including variegation of leaves is picked up by horticulturists for propagation.
5. Foliage plants are grown for adorning our verandahs and passages.
6. The foliage of some plants is economically important, e.g. Tea.

Angiosperms: Origin And Evolution

Angiosperms, more commonly known as flowering plants are the dominant seed-bearing plants of the present day, consisting of a vast and varied assemblage of about 2,34,000 species (Thorne, 1992). They are commonly considered "modern" seed-plants and geologically young.

Ancestors of Angiosperms

The identity of the ancestors of the flowering plants is a most difficult problem which is as yet far from being solved. There has been considerable difference of opinion as to the facts about the origin of angiosperms. Neither the time nor the place of their origin is known for certain. The nature of their ancestors is yet another problematic aspect. Several groups of plants have been considered as ancestral to angiosperms.

(i) Bennettilean ancestry

Saporta and Marion (1885), and later Arber and Parkin (1907) proposed the Bennettitales, the extinct group of gymnosperms related to cycadophyta, to be the possible ancestors of angiosperms. The resemblance in structure between the strobili of the Mesozoic genus cycadeoidea and the flowers of *Magnolia* has been pointed out by these investigators. But this resemblance is wholly superficial, as they are alike only in having an elongated axis on which the protective bracts, microsporophylls and megasporphylls are arranged successively from below upward. However, the differences are many. The microsporophylls (stamens) of *Magnolia* (as in other primitive angiosperms) are free and arranged spirally on the axis, but in Bennettitales, they are whorled and mostly connate. The megasporophylls of Bennettitals are greatly reduced, simplified stalk-like structures, each bearing a solitary terminal erect ovule. Between these stalk-like megasporophylls and alternating with them, are sterile organs (interseminal scales) which appear to be modified sterilized megasporophylls. These sterile scales, with their tightly packed expanded apices, form a kind of protective armour around the ovules. Protection of the ovules is achieved, therefore, in a very different way from that found in the angiosperms. Another special feature of Bennettitales is formation of the micropylar tube in the ovules of Bennettitales which is unknown in angiosperms and the pollen grains are shed on the stigma of the carpel (megasporophyll). Again, the seeds of Bennettitales are non-endospermic with a large embryo while those of primitive angiosperms are with copious endosperm and a small embryo. All these facts indicate that the Bennettitales cannot have been the ancestors of the angiosperms. But the similarities with angiosperms, most probably, might have resulted due to a common ancestry and parallel evolution. In fact, the two groups in question did have a common origin from seed ferns as postulated by Arber and Parking (1907). They might have diverged very early.

(ii) Gnetalean ancestry

Richard von Wettstein in his Handbuch der Systematische Botanik (1901), rearranged and modified Engler's system and emphasized a close relationship of Gnetales with angiosperms. Markgraf (1930) and later on Fagerlind (1947) strongly support this view and the latter demonstrated the morphological homology between the flowers of *Gnetum, Ephedra* and *Welwitschia* and postulated that these and pro-angiosperms have evolved from a common ancestor. The Gnetales resemble angiosperm in many respects. They have two cotyledons and unlike all other gymnosperms have vessels in their secondary wood, two integuments and net veined leaves.

Gnetales, in many respects, have attained an evolutionary level higher than that of some of the primitive angiosperms. For instance, the living genera *Ephedra, Welwitschia* and *Gnetum* have vessels in the secondary wood, yet some angiosperm families such as Winteraceae (woody) and Nymphaeceae (herbaceous) have xylem completely devoid of them. Further more, special investigations (Thompson

1918) have shown that the vessels of Gnetales originated in an entirely different way from those of Angiosperms.

(iii) Isoetalean Ancestry of Monocotyledons

Ferns, both eusporangiate as well as leptosporangiate and fern allies like Lycopodiales Isoetales etc. have been shown to possess many common features with those of the monocotyledons. Engler and his associates have postulated the probable origin of monocotyledons from various groups of pteridophytes through an intermediate and hypothetical group, the protangiosperms. This latter group, according to Engler, is not represented in the fossils as many of them were herbaceous. Engler also postulated direct derivation of monocotyledons from ophioglossaceae, on the basis of similarities in their vascular bundles. Similarities in the embryo of monocotyledons and ferns have been recalled by others. Campbell (1928), however,opined that the herbaceous character in angiosperm is primitive, inherited from filicinean ancestors. According to him, the existing heterosporous genera especially *Isoetes* shows interesting suggestions of a possible relationship with monocotyledons. *Isoetes* is predominantly herbaceous and geophilous. It is also either aquatic or amphibious. Like most of the Filicineae, it is found in humid tropics, a habitat, which is also characteristics of a large number of monocotyledons. Campbell also pointed out the marked similarity in habit and resemblances in the embryo and anatomy of the older sporophyte between Isoetales and some other lower aquatic monocotyledons.

This theory of Pteridophytes ancestry is highly unacceptable as the monocotyledons are now considered as most advanced group of angiosperms and derived from Dicotyledons.

(iv) Coniferalean ancestry of Amentiferae

This theory has been proposed by Eichler (1875), Engler (1882, 1892), Engler and Prantl (1924), Rendle (1904, 1930), Hagerup (1934, 1936) and Doyle (1945). These authors have pointed out the resemblances of angiosperms to conifers and considered the amentiferous group as the most primitive dicotyledons in their taxonomic treatments. The inflorescences of the amentifer like Casuarinaceae, Salicaceae, Fagaceae, etc. with their simple and naked flowers are compared with those of the conifers.

This theory is not acceptable because the amentiferae group is now considered as an advanced group of angiosperms. The advanced features in Amentiferae include anemophilous flowers, unisexual flowers, naked flowers etc. The wood anatomical data suggest that Amentifereae are highly advanced. Hence coniferales as the ancestors of angiosperms and Amentiferae as primitive group of angiosperms is ruled out.

(v) Pteridospermean Ancestry

Pteridosperms (Seed ferns) were considered as ancestors of Angiosperms by Long (1966). Features like reticulate venation, monopodial branching, presence of cambium, presence of microsporophylls and megasporphylls on the same plant, origin of sepals from leaves and petals from sepals and stamens, development of triploid endosperm as extreme reduction of female gametophyte, similarties of seed structure and existence of one or several ovules subtended by a cupule together with information provided by *Glossopteris* reproductive structures are enough to bring seed ferns (Pteridosperms) closest to Angiosperms.

But Pteridosperm ancestry of angiosperms appear to be untenable because of two serious objections. The scalariform xylem elements never occur in Pteridosperms while they are common in Angiosperms. No satisfactory explanation is given for cupule as an equivalent of carpellary wall in case of multiovulate cupules.

(vi) Pentoxylolean ancestory

Meeuse (1961) listed a number of features of Pentoxylales, a group of fossil pteriodsperms, to be similar to *Pandanus*. These include: erect habit, dioecious nature, tuft of leaves, axillary inflorescence, peduncle with tracheids and spiral thickening and bordered pitting, two layered seed coat of which the inner one is usually tanniferous, fleshy sarcotesta enclosing seeds, endospermic seeds and minute embryo.

Inspite of these resemblances, authors like Pant and Kidwai (1971), hold that they could equally be the result of parallel evolution.

(vii) Caytonialean Ancestry

This theory was proposed by Thomas (1925, 1936) and supported by Stebbins (1974). Caytoniales are fossil plants of middle Jurassic period. These plants have angiosperm-like anthers, produced in groups or single on branching pinnate structures, which may be described as sporophylls. Such structures are comparable with the branched stamens found in *Ricinus*, *Hypericum* and *Calothamnus*. Thomas also explained how angiospermy actually come about with the help of caytoniales. He suggested that the carpel wall of angiosperms may represent a pair of concrescent cupules and that the possible origin of the stigma should be considered in the light of these ancient forms.

Caytoniales, however, have now been shown to have relationships with Pteridosperms and classified as Mesozoic remnants of that group. The ancestors of angiosperms must have had open megasporophylls with exposed ovules, as evident from the morphological studies on the nature of their carpel. Thus, the ovary-like pouches of caytoniales cannot be taken to be the forerunners of angiosperm carpel.

Further the presence of pollination drop, direct pollination, fleshy canals in the inner side of the curved cupules, highly cuticularised winged pollen and absence of connective- like structure in tetralocular synangia of caytoniales negate the theory of caytonialean ancestry of Angiosperms.

(viii) Durian Theory

Corner, with his first hand knowledge of tropical forests, formulated a novel theory (1949) of the origin of angiosperms. He suggested that the primitive angiosperms must have been a mesophytic, tropical, cycad-like tree with closely set compound leaves, probably monocarpic and producing a large terminal cluster of arillate follicles. *Durio zibethinus* Murr., a member of Bombaceae from Burmese and Malayan forests, was considered by this author, as a surviving model of primitive angiosperms. It is a cauliflorous tree and bears large, coloured, loculicidal spiny capsules with felshy arillate seeds. There are about 45 angiospermous families, which show arillate genera mostly distributed in the tropics.

This theory has been criticised by a number of morphologists including Pijl (1952), Parkin (1953), Metcalfe (1954) and Eames (1961), and thus does not find adequate support.

The Origin of Monocotyledons

Many different hypothesis have been put forward to explain the origin of monocots but none appears to be wholly satisfactory. Engler and his associates, for example, considered Isoetales, Ophioglossals and a few other pteridophytes as ancestral to monocots and have maintained that herbaceous monocots are more primitive than woody dicotyledons. Contrary to this view, it is now generally accepted that the woody habit is more primitive and monocots most probably have diverged from some primitive dicotyledons in the early history of evolution. This also implies that angiosperms as a group are taken to be monophyletic.

The dicot families such as Lardizabalaceae, Menispermaceae, Ranunculaceae and Berberidaceae have most often been considered as possible ancestors of monocots. According to Hutchinson (1959), monocots arose from Ranunculaceae. However, the pollen in Ranunculaceae is triocolpate, pantocolpate or pantoporate and never monocolpate, which is a special characteristic of the majority of the monocots. Since the monocolpate is the most primitive type of pollen in angiosperms, monocots are consequently more primitive in their pollen than Lardizabalaceae, Ranunculaceae and related families. The ancestors of monocots must therefore be found among the dicots with primitive monocolpate pollen (Takhtajan, 1954, 1961; Eames, 1961).

Comparative anatomical studies have shown that vessels originated independently in dicots and monocots (Cheadle, 1953). If this is so, the ancestors of moncots must have been the vesselless dicots such as Magnoliales and Nymphaeales. Takhtajan (1943, 1959, 1961) and Cronquist (1968) are of the opinion that the immediate ancestors of monocots were most likely some extinct vesselless herbaceous plants with apocarpous gynoecia and monocolpate pollen, which probably had much in common with the modern Nymphaeales. Similar views were also held by Hallier (1905), Arber (1925) and Parkin (1923). Takhtajan (1969) and Cronquist (1968) have also attempted to bring out several common features between the primitive monocots and Nymphaeales. These features include apocarpous gynoecia with “diffuse” placentation, stems with scattered closed vascular bundles, more or less reduced primary root and their root structure, features of leaf structure and development. Indeed, various other authors have regarded Nymphaeaceae as monocots (Trecul 1845, Seidel 1869, Schaffner 1904, 1929, 1934 and Cook 1906). The only difference between primitive monocots and Nymphaeales is the presence of two cotyledons in the latter.

Monocots are characterized by a single cotyledons in their embryos while the great majority of dicots have two cotyledons. Hegelmaier (1874, 1878), on the basis of comparative study of various dicot, and monocot embryos, suggested that the monocot embryos arose as a result of the failure of one of the two cotyledons of a typical dicot embryo to develop. This abortion-hypothesis was subsequently propagated by Henslow (1893, 1911), Winkler (1931), Metcalfe (1936), Eames (1961) and many others. Stebbins (1974), on the other hand, believed that the single cotyledon of monocots is derived through intercalary concrescence of the petioles of two original cotyledons by way of syncotyly and subsequent reduction of lobes. He, however, did not agree with the nymphaealean ancestory of monocots and proposed that they might have diverged early in the history from a common stock. In his opinion, vessels arose later in the evolution of monocots and the group is most probably derived from *Drymis*-like ancestors with short internodes and vesselless wood.

They evolved in open climate which was seasonally wet and dry. The primitive monocot habit thus is exemplified by geophytic habit with radical leaves and branched scapes somewhat similar to the present day *Aspidistra, Curculigo, Chlorophyllum*- like members of the liliales. Aquatic monocotyledons, as well as xeric forms and those having arboreal growth habit are regarded as secondary derivatives.

Origin and Evolution of Gymnosperms

The gymnosperms include naked seed plants ranking second in position, only next to angiosperms, among the dominant flora on earth today. This group of plants dominated the earth in the remote past during late Palaezoic and the Mesozoic eras. The gymnosperms include such ancient groups of seed bearing plants that their origin can be traced only by studying and analyzing the fragmentary fossil records. The problem further becomes difficult because the fossil remains are found mostly in the form of isolated plant parts, viz., leaves, stem, strobili, sporangia, spores, roots etc. These separate plant parts have been given generic names (i.e. form genera or organ genera) and extensive studies are being carried out to reconstruct the complete plants out of them. The reconstruction of plants is mainly done by demonstrating the physical connections between the two or more form of genera.

One of the most outstanding conclusions regarding the origin of gymnosperms was proposed by Beck (1960). He regarded the two organ genera of the upper Devonian period (i) *Archaeopteris* and (ii) *Callixylon* as the possible ancesters. The form genus – *Archaeopteris* was described for large fern-like leaves (Dawson, 1871). The fossil was first discovered in the form of compression from the upper Devonian strata of eastern North America. It was universally accepted as the free sporing foliage of a late Devonian fern (Arnold, 1939). The genus was characterized in having (i) Opposite or sub-opposite sterile or fertile pinnae borne on a common rachis, and (ii) the fertile pinnules having one or two rows of fusiform sporangia borne or adaxial surface. The other form genus *Callixylon* was found in the form of petrified fossils from the same age and locality. The specimen was characterized by having (i) size range from the fragments of small, detached twigs and branches to the gigantic trunks, (ii) large pith having thin-walled cells, (iii) mesarch primary xylem (iv) secondary xylem having tracheids with spiral, reticulate and pitted thickenings (v) secondary xylem was compact pycnoxylic with medullary rays and the xylem tracheids having 2-3 rows of circular bordered pits in their radial walls. Such type of stem anatomy is the characteristics of present day conifers and thus, the form genus *Callixylon* was assigned as having coniferous alliance. Beck (1960) made an interesting discovery of a specimen from the upper Devonian beds of New York State in which the *Archaeopteris*- like frond was in organic connection with the *Callixylon*- like axis. This plant having combinations of the two form genera (*Archaeopteris* and *Callixylon*) was placed by Beck (1960) in new class- Progymnospermopsida and given the generic name – *Archaeopteris*. Based on the detailed study of this plant and its correlation with other gymnosperms, Beck (1970) proposed that the group Progymnospermopsida seems to be immediate ancestor of seed plants (gymnosperms).

It was also postulated that one evolutionary line form Progymnosperms led to the seed ferns (Pteridospermophyta) and the other to the conifers displaying the monophyletic origin (Beck, 1976). Regarding the origin of Progymnosperms, it seems probably that they originated from Trimerophytopsida, the most ancient and primitive group of vascular plants of lower and middle Devonian period. The structural similarities between Progymnosperms and Trimerophytes such as, (i) dichotomous and pseudomonopodial branching (ii) well developed and massive protostele, (iii) mesarch (or centrarch) protoxylem (iv) typical fusiform or oblong sporangia borne terminally on the ultimate branches, and (v) liberation of spores through a longitudinal slit in the sporoangial wall, led Andrews, Gensel and Kasper (1975) to postulate that progymnosperms probably originated from Trimerophytes and the genus *Oocampsa* serving as the connecting link between the two groups.

Regarding the orgin of Cycadales, the various studies conclusively indicate that this group arose in the Palaeozoic era, the time when Pteridophytes and Cordaitales were all flourishing. Thus, any one of these groups could have acted as the possible ancestors of the present day cycads. Out of these groups, the Pteridosperms the most primitive dominant seed flora in the Upper Carboniferous period of Palaeozoic era such as, *Lyginopteris*, *Medullosa*, etc. seem to be more potent ancestors (Steward and Rothwell, 1993). They had most significant similarties with cycadales viz., (i) pinnate foliage, (ii) circinate vernation, (iii) presence of armour of persistant leaf bases on the main trunk (iv) large pith and cortex with mucilage canals (v) similar structure of steles and monoxylic secondary wood (vi) absence of well organized female cone and (vii) presence of motile and ciliated spermatozoids. Moreover, the cycadophytes were predominant and wide spread during the Jurassic period of Mesozoic era when the Pteridosperms had declined. Therefore, it seems more reasonable that the Pteridosperms must have given the origin to the Cycadales and slowly declined and disappeared.

The extinct cycad- like plants are included in the group Cycadeoidales (Bennettiales) show close affinities with cycads as well as the angiosperms. They also resemble pteridosperms in having growth habit similar to Lyginopteridaceae and internal organization similar to Medullosaceae consisting of syndetocheilic types of stomata. These studies clearly indicate that the cycadeoids and cycads probably originated from the common ancestors among the pteridosperms. The cycadeoids occupy the terminal position in the line of gymnosperm evolution and due to presence of peculiar hermaphrodite flower like strobilii, they are considered as forerunners of the present day angiosperms (Crane, 1988, Doyle and Donoghue, 1987). Both cycadeoids and cycads were considered as distinct group because (i) they differ in their cone structure and (ii) ontogeny of stomata (the stomata of cycadeoids are syndetocheilic whereas those of cycads are ahplocheilic) and apparent similarities must have been due to a common origin from pteridosperms and parallel evolution.

Regarding the origin of Ginkgoales and Coniferales, Florin (1938-1945) postulated that Palaeozoic Cordaitales might be the possible ancestors later on. Investigations carried out by Beck (1970) and Stewart and Rothwell (1993) concluded that the extinct genus *Archaeopteris* of progymnospermophyta displays several characters which are common with the Cordaitales, Voltziales, Coniferales and Taxales such as (i) simple leaves arranged spirally on the axis, (ii) primary vasculature eustelic (iii) secondary xylem pycnoxylic with uniseriate medullary rays. Based on these studies, it was suggested that the Devonian group Archaeopteridales gave the origin of both Cordaitales and Coniferophytes.

Origin and Evolution of Stelar System of Gymnosperms

The term stele is usually applied to designate the unit of vascular system. The gymnosperms are characterized by having an advanced type of primary vascular system usually referred as eustele which originated from the primitive protostele i.e., the central solid core of xylem surrounded by phloem followed by pericycle.

There are two main views regarding the origin of advanced eustelic vascular cylinder from the primitive protostele.

(1) The first view was proposed by Jeffrey in 1917. According to this view, the most primitive type of stele is a protostele. The first step in the stelar evolution was the enclosure of cortical tissue within the stele resulting in the formation of central parenchymatous pith. Such type of stele is called tubular siphonostele. He opined that the pith originated extrastelary from the cortex. Later on during the course of evolution the siphonostele was dissected at many places due to formation of leaf gaps. Generally, the leaf traces arise in stems result in the formation of leaf gaps just above the points of departure of leaf traces. This results dissection of tubular siphonostele into many discrete bundles or meristeles. Such type of stele is called dictyostele and occurs in many pteridophytic ferns. Jeffrey was of the opinion that if the internal endodermis, internal pericycle and the internal phloem are last, the dictyostele becomes a true eustele having conjoint and collateral vascular bundles.

(2) The second view was proposed by Namboodiri and Beck (1968). This view was based on the fact that the leaf traces in progymnosperms and other gymnosperms do not leave any leaf gaps. An outline of this is briefly given below:

    (i) The primitive stele is protostele consisting of a central solid core of xylem surrounded by phloem. The ribs present in the protostele represent the point of origin of radially diverging leaf traces. There are ribs in the stele of some primitive progymnosperms, e.g. *Aneurophyton, Tetraxylopteris,* etc.

(ii) In the next stage; the central longitudinal column was dissected into three or more longitudinal columns with the origin of parenchymatous pith in the central region (i.e. medullation). Such type of stele is represented by upper Devonian. *Archaeopteris, Calamopitys* etc.

(iii) The longitudinal columns move more towards periphery due to appearance of massive pith in the centre. Each longitudinal sympodial column divides tangentially near the node. The division results into the formation of an outer leaf trace bundle and an inner reparatory strand. The reparatory strand continues its upward course without the formation of leaf gap. This type of vascular system is found in the main axis of the frond of *Archaeopteris, Calamopits,* etc.

(iv) The next step of evolution is the change in the nature of division of sympodial bundle. Instead of tangential division, they divide by radial divisions so that the leaf and reparatory strand continues upwards as the sympodial bundle and divides further. Such types of steles are found in the Carboniferous pteriodospermophyta (seed ferns) – *Lyginopteris* and also in some living conifers.

(v) Further addition in the number of leaf traces and change in their direction and divergence leads to the vascular pattern of *Ginkgo*, *Ephedra* and Conifers, and it resulted in the formation of typical eustelic vascular system is gymnosperms.

Origin of Gymnospermous leaf

Bower (1884), for the first time, proposed that compound leaves of cycads and ferns have evolved from the three dimensional dichotomized branching systems of primitive vascular plants. Later on Zimmermann (1952) proposed 'telome theory' and visualized that fronds of cycadophytes have evolved by overtopping, plantation and webbing of the branch system of Middle and Upper Devonian primitive vascular plants like *Protopteridium, Aneurophyton* or *Tetraxylopteris*. Seck (1957) and Meeuse (1963) proposed the view that simple leaves of confierophytes probably evolved in the progymnosperms (*Archaeopteris*) through the process of plantation and lamination of ultimate appendages of a system composed of several orders of branches. The compound leaves of cycads, on the other hand, probably evolved from radially symmetrical two to four orders of branching system of the Aneurophytes.

Origin and Evolution of Ovule (And Seed)

The ovule of gymnosperm may be defined as an integumented indehiscent megasporangium in which the single functional megaspore develops into a megagametophyte. It consists of an envelope (the integument) with a micropyle and a megasporangium (the nucellus) inside which there is a female gametophyte composed of nutritive tissue and several archegonia. After fertilization, it develops an embryo within the nutritive tissue of megagametophyte and becomes a seed on maturation.

Before discussing the origin of ovule and seed, the concept of homospory and heterospory and its role in vascular plants must be clearly understood. It is generally agreed that homospory is primitive condition and heterospory is derived. It is also true that heterospory preceded the evolution of seeds. Palaeobotanical evidences suggest that all the vascular plants, prior to Middle Devonian, were homosporous i.e., the isospores produced bisexual (monoecious) exosporic gametophytes. The first evidence of heterospory was reported in the Middle Devonian – *Chauleria* where the sporangia produced two types of spores (the microspores ranging in size from 33 to 48 µm and the megaspores ranging from 700 to 900 µm in diameter). There are other evidences (e.g., *Barinophyton citrulliforme*) which suggest that heterospory may have first appeared in plants where each sporangium contained both microspores and megaspores. This condition was followed by plants which produced separate microsporangia (with large number of small microspores) and megasporangia (with reduced number of large megaspores). Reduction in number of megaspores, alongwith some other changes in the megasporangium, must have took place in the origin of preovule and finally to the ovule and seed. Some of the important evolutionary events in the origin and evolution of ovule may be as follows:

(i) Reduction in the number of functional megaspore upto one in each megasporangium.

(ii) Retention of megaspore within the megasporangium.

(iii) Formation of an integument that ended into a micropyle.

(iv) Development of female gametophyte within the megaspore (i.e., endosporic) and retention of megagametophyte within the indehiscent megasporangium (nucellus).

(v) Elaboration of the apex of nucellus for receiving pollen.

The palaeobotanical evidences in support of all the above mentioned evolutionary events are not complete. However, evidences are available which indicate that integumentary envelope of ovules have evolved directly from the fertile and sterile telome trusses. Long (1960) studied the seeds of certain carboniferrous pteridosperms- *Genomosperma kidstonii* and *G. latens*. The nucellus of the preovule (seed), *G. kidstoni* was found to be surrounded by a whorl of eight free filamentous telomes. The telomes flare outward and are fused only at their bases. There is no micropyle. Further advancement towards the formation of integument is represented by the ovule of *G. latens*, where the eight integumentary lobes are apically appressed forming a rudimentary ‘micropyle’ and fused basally for about one third of their length. The integumentary lobes are fused for about one half in the preovule of *Physostoma elegans* and the fusion is almost complete in the seeds of *Archaeosperma* and *Eurystoma angulare*. The complete fusion is shown by the integument of the seed of *Stamnostoma huttonense*, where a micropyle is formed.