Semester	Course	Hours	Credit	Sub.Code	Marks		
					Internal	External	Total
II	CC5	6	4	18KP2B05	25	75	100

ANATOMY, EMBRYOLOGY AND MICROTECHNIQUES

UNIT I: ANATOMY

Meristem organization of shoot and root apices of Angiosperms. Theories of Root and Shoot Apex, Cambium and its derivative tissues, Differentiation of secondary xylem and secondary phloem, Anatomy in Relation to taxonomy.

UNIT II:

Anatomical features of Root, Stem and Leaf of Dicot and Monocot. Normal and Anomalous secondary growth in Dicot stem- Aristolochia, Nyctanthes and Monocot stem- Dracena. Nodal anatomy- Types of nodes and origin of bud traces. Wood anatomy in relation to phylogeny.

UNIT III:

Microsporogenesis- Structure and development of Microspororangium- development of Male gametophyte, Megasporogenesis- Structure and development of Megasporangium- Types of ovule, Development of female gametophyte. Fertilization, Development of Dicot and Monocot Embryo.

Preapred By :

1.Dr.V.Latha unit - 1

2.Dr.K.Tamilselvi unit -2,3

Meristem organization of shoot and root apices of Angiosperms

The Shoot Apex:

The terminal part of the shoot with the leaf primordia is the shoot apex where primary organisation of the shoot is initiated.

In size and shape it varies enormously, but in a general way it can be said that the shoot apex is more or less convex in longitudinal section.

The apical meristem widens considerably before the initiation of the leaf and it again becomes narrow after the appearance of the leaf primordium, thus exhibiting a rhythmic phenomenon.

As already reported the shoot apex of angiosperms has been the subject of intensive investigation for pretty long time, and a number of theories (discussed) have been enunciated regarding the growth and differentiation of the same.

The generally accepted concept, tunica-corpus theory, demands that the tunica with one or few layers of cells forms an envelope round the centrally-located initials of the corpus.

The number of layers of tunica may vary (one to nine) in the same family, genus and even in the same plant at different stages of growth. Two types of cells have been recognised in the tunica.

One or few initials forming a central apical zone having larger size, more prominent nuclei and conspicuous vacuoles. The cells of this zone take light strain.

The second zone consisting of comparatively smaller and deeply staining cells occur on the sides of the apex between the initials and the leaf primordium.

According to internal arrangement, the corpus may be of two types—(1) the usual angiospermic type with three main zones, viz., (a) a zone of central mother cells representing the corpus initials, just below the apical portion of the tunica, (b) rib meristem, and (c) flank meristem, the last two appearing as continuations of central mother cells; (2) the Opuntia type, in which, a cup-shaped cambium-like transitional zone between the mother cells and other meristems have been recognised (Fig.

532A—5 & 6).

This zone which is always associated with leaf primordium differs from the rest in that the height and diameter vary considerably during the plastochron. It is considered by some (Philipson, 1954) as only a temporary feature, because it disappears towards the end of the plastochron.

Another concept about apical meristem developed on the basis of the rate of mitotic activity suggesting two zones—(1) a central apical zone with tunica and corpus initials having less frequent activity, and (2) a peripheral zone with pronounced mitotic cell division.

The vacuolated distal part of the apical meristem, according to them is of no significance in vegetative growth, the peripheral meristem with actively dividing cell and the rib meristem play the main roles in building the shoot.

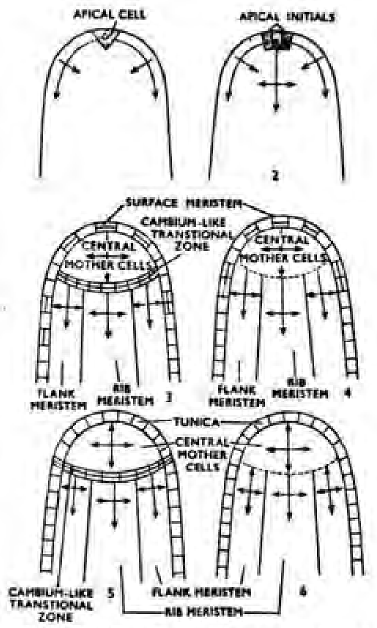


Fig. 532A. Shoot apics (diagrammatic). 1. A pteridaphyta with a single apical cell; 2. Same with apical initials; 3. *Gingko* type; 4. *Crypto-meria-Abies* types; 5. *Opuntia* type; 6. Usual angiospermic type. (*After Popham*).

The Root Apex:

In comparison to the stem apex the apical meristem of the root is simpler, because of the absence of nodes and internodes and lateral appendages. But it has a protective cap, which acts as the buffer between the root-tip and the soil particles.

As cap occupies the terminal position, the apical meristem is subterminal here. Curiously enough, growth in the root-tip proceeds in two directions opposite to each other—towards the tip in the cap and away from the tip in the root proper.

Though histogen theory has been practically discarded in case of stem apex, it is followed in interpreting the structure and growth of root apex. The apical meristem here is rather short.

Considerable variations exist in the relation between the cap and the tip. In fact, root apices are of a few types depending on the mode of origin of cap and relations between histogens and primary tissue regions of the root proper.

In angiosperms three groups of initials usually occur at the root apex. In dicotyledons (Fig. 533C), of the three groups, the terminal one forms the dermatogen and the cap; the median one forms the periblem; and the innermost one gives rise to the plerome.

So here the cap and dermatogen have common origin. Thus cap may be considered a specialised development of the epidermis.

In monocotyledons (Fig. 533D), the outermost group of initials produces the cap; the medium one, the dermatogen and periblem; and the innermost one, the plerome.

The group of initials forming dermatogen and periblem is usually one-layered, but it may be two or three layers in thickness. Independent origin of the cap is a notable feature. The histogen concerned with the formation of the cap is referred to as calyptrogen.

The lateral and adventitious roots show same type of organisation.

In recent years many investigators (Jensen, Clowes, and others) have claimed that a zone of low mitotic activity composed of the cells of the central part of the promeristem occur. It has been called quiscent centre.

A theory—Kőrper-Kappe theory, more or less similar to the tunica-corpus of the shoot apex, was enunciated on the basis of planes of cell division. According to this theory there are two regions, outer (Kappe) and inner (Korper), and the cells divide in a pattern known as T-division.

Kappe cells first divide horizontally and the derivatives divide at right angles to the plane of first division—the planes of two thus forming a T. In the inner region Korper T is inverted as the second division takes place in the upper daugher cells.

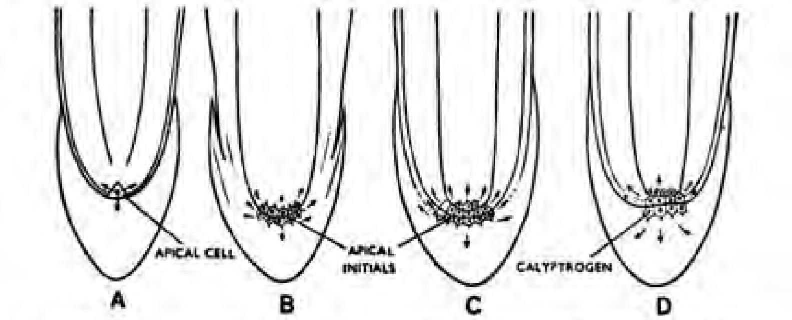


Fig. 533. Root apice. (diagrammatic)—A. Type found in pteridophytes with solitary apical cell. B. As found in gymnosperms. C. As found in dicotyledons. D. As found in monocotyledons.

Theories of Root

The following points highlight the top three theories of root apical meristem in plants. The theories are: 1. Apical Cell Theory 2. Histogen Theory 3. Korper-Kappe Theory.

1. Apical Cell Theory:

This theory was proposed by Nageli who drew the attention to the occurrence of a single apical cell or apical initial that composes the root meristem. A single apical cell is present only in vascular cryptogams, e.g. Equisetum, Adiantum and Polypodium etc. The apical initial is tetrahedral in shape and generates root cap from one side.

The other three sides donate cells to form epidermis, cortex and vascular cylinder. In other words all tissues that compose a mature root including root cap are the derivatives of a single apical cell. Apical cell theory is confined to vascular cryptogams only as the root apical meristem of flowering plants does not have a single apical cell.

2. Histogen Theory:

Hanstein in 1868 advocated the theory. According to Hanstein root apical meristem consists of three cell-initiating regions called histogens (Fig. 7.22). The histogens are called dermatogen, periblem and plerome that respectfully form epidermis, cortex and vascular cylinder that are present in a mature root.

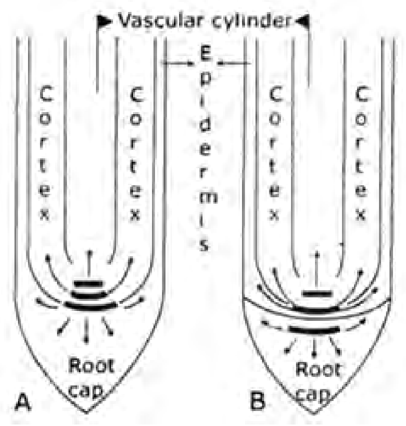


Figure 7.22

Schematic diagram of root apex based on Histogen theory. A. Root apex of *Raphanus sativa*. B. Root apex of *Zea mays* where root cap has its own histogen, i.e. Calyptrogen. Broad lines indicate histogens. Arrows indicate the direction of cell formation.

The derivatives of dermatogen vary. In Zea mays (monocot) dermatogen generates root cap only and this histogen is referred to as calyptrogen. In Brassica (dicot) dermatogen generates both protoderm and root cap and this histogen is referred to as dermatocalyptrogen.

Histogen theory explains both root and shoot apical meristem. This theory attributes specific destinies to the derivatives of the three histogens. Though histogen theory is abandoned to explain shoot apex, Eames and MacDaniels illustrated the root apical meristem on the basis of histogen concept.

3. Korper-Kappe Theory:

This theory of root meristem was proposed in 1917 by Schiiepp who regarded the occurrence of two systems of cell seriation that characterize the root apex with reference to planes of cell division in its parts.

Korper-kappe concept is also referred to as body-cap concept (Korper = body and kappe = cap) and the concept illustrates distinct type of cell wall pattern formation during cell division. The body-cap concept is illustrated below on analyzing the divisions in the derivatives of apical cell (Fig. 7.23).

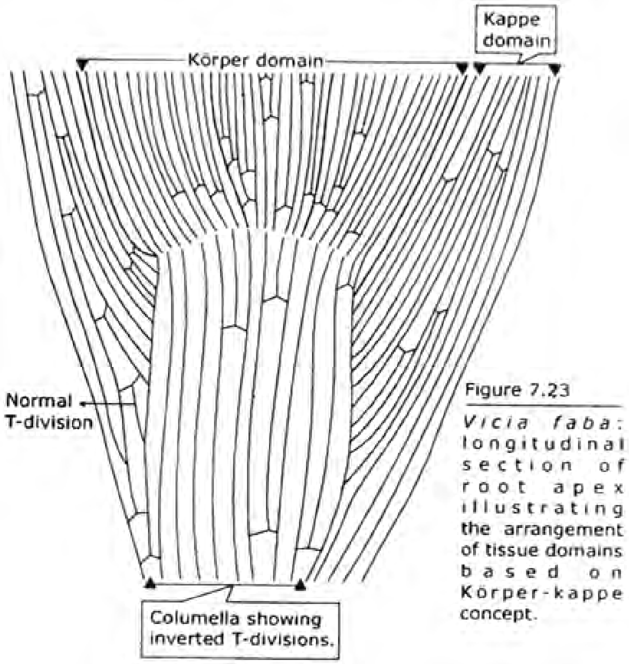


Figure 7.23

Vicia faba: longitudinal section of root apex illustrating the arrangement of tissue domains based on Körper-kappe concept.

The root meristem exhibits multicellular structure. It consists of conspicuous longitudinal files of cells. During growth the root changes in diameter. This happens due to cell divisions that occur in such a way that a single longitudinal file of cells becomes double files. The initial cell divides transversely. The two cells thus formed one has the capability of cell division. This cell divides longitudinally and both the daughter cells inherit the property of cell division.

The daughter cells are parallel in arrangement, share a common wall and divide by transverse partition followed by longitudinal partition in one cell. The sequences of wall formation when viewed together appear to form a configuration resembling the letter ‘T’ or ‘Y’. Such divisions are described as T-divisions. Continuous T-divisions result in the formation of double-rowed region over a single rowed region.

It is the T-division that characterizes korper and kappe. In the kappe the initial cell first divides transversely and forms two cells. The daughter cell that faces the root apex inherits the initial function. It divides longitudinally. The two cells thus formed have the capability of cell division.

When transverse and longitudinal partition are viewed together the combined cell walls appear as ‘T’ that is right-way-up. When such division continues it is observed that a single rowed region is left behind over the double-rowed region. This occurs in downwardly pointed roots.

In the korper the initial cell first divides by transverse partition and forms two cells. The daughter cell that faces the base of root, i.e. away from the apex inherits the initial function.

It divides longitudinally and the two daughter cells thus formed have the potentiality of cell division. The daughter cells divide by transverse partitions followed by longitudinal partitions. When transverse and longitudinal partitions are viewed together the cell walls form a configuration resembling an inverted ‘T’.

Korper and kappe-these two zones of root are delimited by planes of cell division. The zones exhibit clear boundary when they originate from separate initials, e.g. root with calyptrogen. The zones do not exhibit sharp demarcation line when they are the derivatives of same apical cell. In root with dermatocalyptrogen the cap extends into protoderm.

The central part of root cap is the columella where the cells are arranged in longitudinal files. These cells seldom divide. When division occurs the partition walls form the configuration of an inverted ‘T’ that is observed in the korper. The ‘T’ has normal configuration in the peripheral region of root cap.

The korper-kappe theory of root apex is comparable with tunica-corpus theory of shoot apex. The body-cap concept and tunica-corpus concept both are based solely on the planes of cell division. Anticlinal division is the characteristic of tunica whereas corpus exhibits both anticlinal and periclinal division.

On the other hand the inverted ‘T’ – and normal ‘T’ pattern of cell wall formation are the characteristic of korper and kappe respectively. The boundaries between korper and kappe, and between tunica and corpus are not always sharply demarcated.

Theories of Shoot apex

The following points highlight the top three theories of shoot apical meristem. The theories are: 1. Apical Cell Theory 2. Histogen Theory 3. Tunica-Corpus Theory.

1. Apical Cell Theory:

Nageli in 1944 advocated this theory. According to this theory the apical meristem consists of a single apical cell (also called apical initial) and this cell is interpreted as the ‘structural and functional unit of apical meristem’. The cell is very large and is shaped like an inverted pyramid.

The apical cell is tetrahedral in shape and has three or four cutting faces among which single face is directed upward and the rest points downward. The side of apical cell that is directed upward is triangular or square in shape and forms a part of the outer surface of the shoot apex (Fig. 7.7).

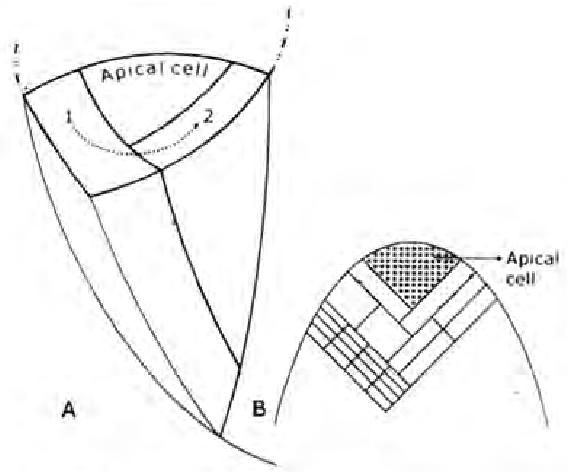


Figure 7.7

A. Diagram showing an apical cell of leptosporangiate fern and its derivatives that are formed in helical succession. The new cells are numbered as 1 & 2. B. Diagram showing a packet of cells formed by an apical cell by division and subdivision.

The cutting faces of apical cell divide in an orderly fashion that is in helical succession.

The cell divides by an asymmetric division; as a result a narrow and flat cell is formed. The next division of the apical cell is also asymmetric. This type of asymmetric division is repeated in the downwardly pointed faces of the apical cell.

As a result all cutting faces have their daughter cells. The daughter cells also divide and form large packet of cells. The packet of cells differentiates and forms different segments of shoot. So the apical cell is regarded as ‘a reserve of one genetically sound cell’.

A single apical cell composing an apical meristem is present in vascular cryptogams. After the discovery of solitary apical cell in vascular cryptogams, it was supposed that such apical meristem might exist in higher plants as well.

Later extensive investigations refuted the universal occurrence of solitary apical cell in a meristem. In higher plants the apical cell theory was replaced by the concept that the different parts of a plant body have independent origin. So the apical cell theory was later superseded by histogen theory.

2. Histogen Theory:

Hanstein in 1868 put forward histogen theory (histogen means tissue builder).

According to this theory the tissues of a plant body originate from a mass of meristem where the following three (histogens) can be distinguished (Fig. 7.8):

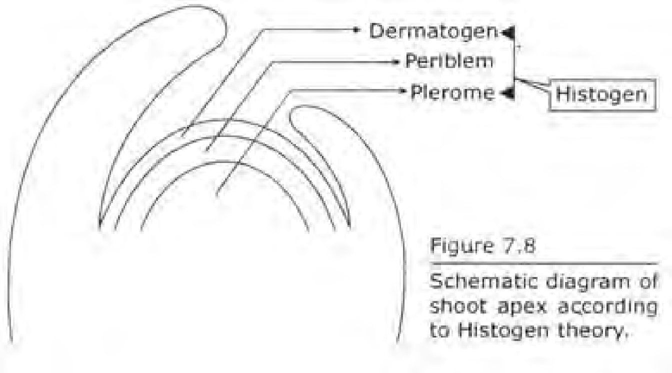


Figure 7.8

Schematic diagram of shoot apex according to Histogen theory.

(a) Dermatogen:

(In Greek meaning skin). It is the outermost layer of the meristem. It gives rise to epidermises of root and stem.

(b) Periblem:

(In Greek meaning clothing). This region occurs internal to dermatogen but peripheral to plerome. This histogen is destined to form cortex of root and shoot and inner tissues of leaves. It surrounds plerome.

(c) Plerome:

(In Greek meaning that this fills). This region gives rise to vascular cylinder of stem and root including pith. It is the central core of stem and root and the cells composing this zone are very irregular. This region is enveloped by a variable number of mantle-like layers which are represented by dermatogen and periblem.

According to Hanstein dermatogen, periblem and plerome arise from independent initials of the apical meristem.

3. Tunica-Corpus Theory:

Schmidt in 1924 postulated tunica- corpus theory on the basis of studies of shoot apices of angiosperm. This theory is concerned with planes of cell division in the apex. In contrast to apical cell theory and histogen theory tunica-corpus theory is applicable only to shoot apex and not to root. Schmidt distinguishes two tissue zones in the shoot apex and termed them as tunica and corpus.

Majority of angiosperm shoot apex exhibits tunica consisting of two layers of cells and corpus (Fig. 7.9A). Researchers designate the layers as L1, L2 and L3 to denote respectively outer layer of tunica, inner layer of tunica and corpus.

Plasmodesmata exist between the cells of tunica and corpus. It is thought that plasmodesma controls the gene expression that leads to the formation of protoderm, ground meristem and provascular tissue.

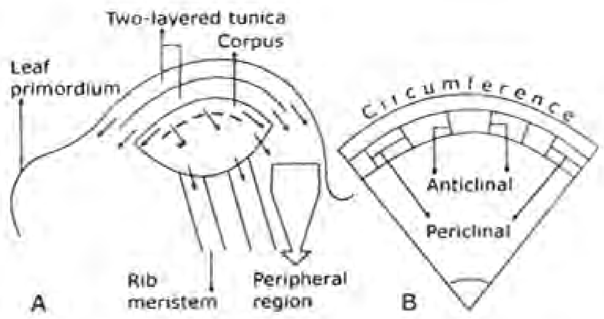


Figure 7.9

A. Diagram illustrating the tunica-corpus organization in dicotyledonous shoot apex. Arrows indicate the direction of cell formation in apical meristem.
B. Schematic representation of anticlinal (= division wall perpendicular to surface) and periclinal (= division wall parallel to circumference) division.

Cambium and its derivative tissues

Secondary Xylem

The xylem formed as a result of the secondary growth from the vascular cambium

Xylem is the vascular tissue responsible for the conduction of water and nutrients from the roots to the shoots and leaves, especially of terrestrial plants. Based on the stage and origin of growth, a xylem may be classified as primary or secondary.

Secondary xylem is the type of xylem formed from secondary growth. In comparison, the primary xylem forms during primary growth. Because of this, the secondary xylem is associated with lateral growth rather than vertical growth as in the primary xylem. Another difference lies on the type of cambium that gives rise to them. The primary xylem comes from the procambium whereas the secondary xylem grows from the vascular cambium.

Secondary xylem is absent in non-woody plants but is present in trees and shrubs. Its cell walls are thickened by deposition of lignin, thereby, rendering mechanical support to such plants.

Secondary xylem consists of tracheids and vessels that are shorter and wider than those of primary xylem. It is also richer in xylem fibers than in primary xylem.

Secondary xylem may show growth rings (or annual rings). In large woody plants, the secondary xylem is differentiated into sapwood and heartwood.

Secondary Phloem

The type of phloem derived from the secondary meristems of a vascular plant.
The phloem is a vascular tissue that is responsible for translocation. Translocation pertains to the process that transports the materials to different parts of a vascular plant. The phloem may be primary or secondary depending on which type of growth it came from or on which type of cambia it came from.
The secondary phloem is a type of phloem that forms from the vascular cambium during the secondary growth. The secondary growth is responsible for the growth in girth in plants, especially trees. The vascular cambium is the meristematic tissue involved in this type of growth. Some of the cells produced by the vascular cambium may differentiate into secondary phloem (others as secondary xylem).

The secondary phloem is located in the stems and roots. It forms inner to the primary phloem. A radial system of phloem rays occurs in the secondary phloem. In terms of cellular components, the secondary phloem has more phloem fibers (occur in bands or patches, and referred to as bast fibers), sieve tubes, phloem parenchyma, and sclereids than the primary phloem. The sieve tubes of secondary phloem are shorter but wider. Thus, there is a rather rapid flow of photosynthate across the sieve tubes of secondary phloem than those of primary phloem.

Anatomy relation to plant taxonomy

In this article we will discuss about the Anatomy in Relation to Plant Taxonomy:-
1. Uses of Anatomy 2. Types of Anatomy 3. Ultra Structural Systematics.

Uses of Anatomy:

Anatomical characters of vegetative and floral parts of flowering plants have been successfully employed to solve taxonomic problems and for the elucidation of phylogenetic relationships. It was Bureau, who for the first time used anatomical characters in plant classification for the delimitation of taxa of various levels, within the family Bignoniaceae.

However, anatomical data have been used extensively as a taxonomic tool only after the nineteenth century. Anatomical data has not only been useful at the higher levels but in certain instances, have been successfully employed even at the specific level. Auguste Mathiew is one of the pioneer taxonomists, who used features of wood anatomy in the description of forest plants in Florae forestiere.

Later, another taxonomist Solereder, discussed the systematic value of anatomical structures in dicotyledons in his classic book Systematische Anatomic der Dicotyledonen, the English translation of which was later published in a modified form in the two-volume book Anatomy of the Dicotyledons by Metcalfe and Chalk.

Types of Anatomy:

1. Vegetative Anatomy:

(a) Leaf Anatomy:

Leaf anatomy provides various characters of taxonomic importance as has been rightly stated by Carlquist, that "the leaf is perhaps anatomically most varied organ of angiosperms and its anatomical variations often concur closely with generic and specific and occasionally familial lines".

Leaf anatomy has been used widely in several taxonomically different groups such as Euphorbiaceae, Cyperaceae and Gramineae of Angiosperms and Coniferae of Gymnosperms.

It has been one of the most reliable characters in grass systematics. For example, the leaf anatomy of several species of Cyperaceae, was studied by Koyama and Govindrajalu and they formulated keys to identify various species of Cyperus, Fuirena, etc. Brown surveyed, 72 genera of grasses and on the basis of their tissue arrangement, six main types were recognized.

However, they could not, be segregated into the two traditional subfamilies, Pooideae and Panicoideae. Similarly, Vidakovie have used several characters of leaf anatomy in differentiating species in Pinus. Taxonomic implication of leaf anatomy of several genera of Musaceae, Zingiberaceae, Xanthorrhoeaceae and Ericaceae have also been established by several workers.

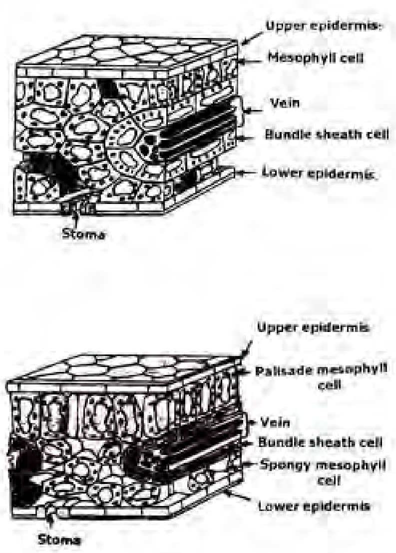


Fig. 8.2 : Cross-section of different types of leaves showing anatomical characters of taxonomic significance

(b) Stem Anatomy:

Stem anatomy has also been long relied on as a taxonomic tool (Fig. 8.3). The two-volume work by Metcalfe & Chalk is an excellent example of an illustrated encyclopaedia of this and of other aspects of plant anatomy, which reveals the taxonomical significance of anatomical characters in plant classification and can be used at various levels from Dicotyledon-

Monocotyledon distinction, to the separation of various species of the same genus. Stem anatomy has particularly proved to be of diagnostic value in the herbaceous members. For example, anatomy of stems has been successfully employed in the delimitation of species of Dioscorea which otherwise are not easily separable on exomorphic grounds.

Carlquist has used anatomical features of the genus Fitchia (Asteraceae) in the classification of various species. Further, it is also possible to identify parents of several hybrids on anatomical grounds.

(c) Petiole Anatomy:

Metcalfe and Chalk and Howard have suggested that the petiole anatomy might also be of taxonomic significance (Fig. 8.4). According to Howard families, genera and even species in some cases may he identified by petiole characters.

(d) Nodal Anatomy:

Nodal anatomy has also gained much importance in taxonomy and phylogeny of angiosperms in recent years. Correlations of nodal anatomy with some other features might help significantly in tracing the phylogeny of angiosperms. A comparative study of nodal anatomy may show important relationships or distinctness of genera or even species (Fig. 8.4).

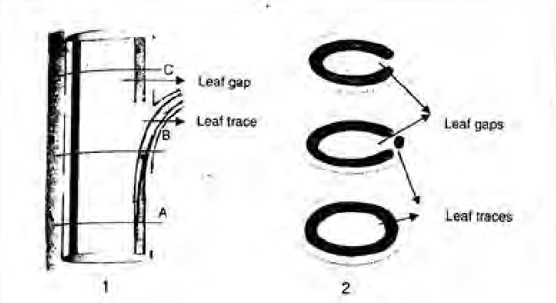


Fig. 8.4 | Diagrammatic representation of leaf trace and leaf gaps ; (1) L.S. through a node showing leaf trace and leaf gap, (2) T.S. through the node illustrated in 1 at levels A-A, B-B, and C-C respectively.

(e) Wood Anatomy:

Wood anatomy has been used at almost all taxonomic levels. Because of their conservative nature, anatomical features of the secondary wood have been very useful in taxonomy and phylogeny.

Along with other lines of evidence, it has been successfully used in deciding the systematic position of primitive vessel less families such as Amborellaceae, Tetracentraceae, Trochodendraceae and Winteraceae, all included under the Magnoliales of angiosperms.

Similarly, due to the presence of specialized wood, it has been agreed by all phylogenists that the Englerian group of primitive angiosperms, namely, Amentiferae (including families like the Salicaceae, Betulaceae, Fagaceae, Juglandaceae, etc.) cannot be considered primitive.

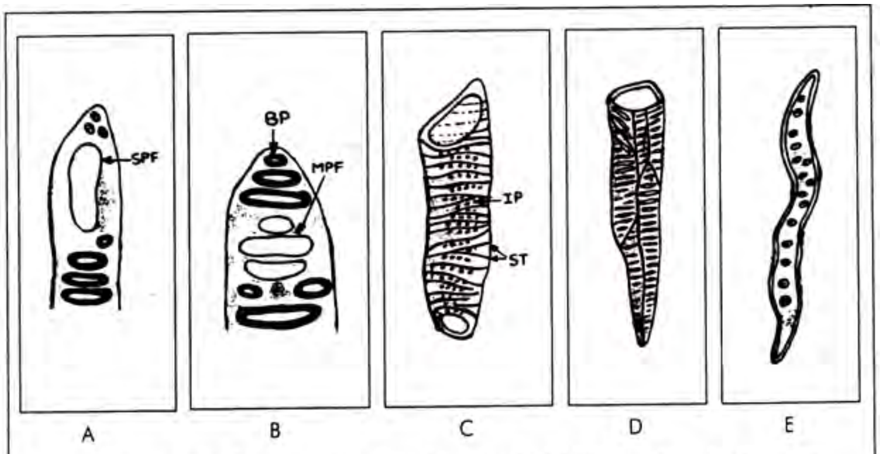


Fig. 8.5 : End walls of some tracheae (vessel members) – (A) With simple perforation plate (SPF); (B) with multiple (scalariform) perforation plates (MPF); (C) Complete tracheae with simple perforation plates, intervessel pitting (IP) and spiral thickening (ST); Tracheids - (D) with scalariform (E) with bordered pits (BP).

(f) Sclereids:

Sclereids, i.e. cells with very thick lignified walls, which are widely distributed in the plant body, have been used as diagnostic tools in several taxa like Connaraceae, Nymphaeaceae, Oleaceae, Theaceae, Umoniaceae, and a few genera of Araceae, Acanthaceae, Ericaceae and Melastomaceae (Fig. 8.6).

In dicots, they are more common in woody forms than in herbaceous ones, but they are extremely rare in monocots, except in certain genera of Araceae, Agavaceae, Arecaceae and a few other families. As they exhibit various shapes, sizes and characteristics of their walls, they have been of some taxonomic significance.

Two main types of sclereids have been recognized, viz. isomorphic and polymorphic types. The sclereid forms may be characteristic of a particular species and thus of taxonomic value.

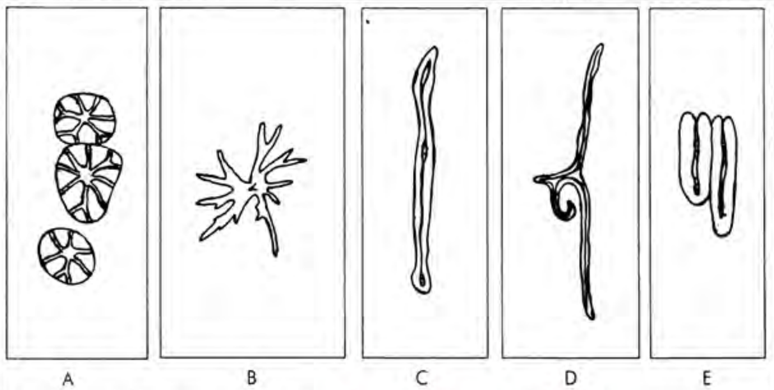


Fig. 8.6 : Different forms of sclereids. (A) Brachysclereids from the pulp of *Pyrus* fruit; (B) Astrosclereids from the leaf of *Trochodendron*; (C) Macrosclereid from the pulp of apple (*Malus*); (D) Trichosclereid from the leaf of *Olea*; (E) Osteosclereid from testa of *Pisum* seed.

(g) Cellular Contents:

Many types of microscopic characters of cell contents i.e., chemical deposits, can serve as important diagnostic tools, and at times prove extremely helpful in delineating species, genera and families.

Crystals and crystalliferous cells have been found to be of systematic importance in several families of angiosperms such as Euphorbiaceae, Leguminosae, Verbenaceae, etc.

2. Floral Anatomy:

As the reproductive organs show a high degree of conservation, they have been widely used in the classifications (Fig. 8.11A). At the same time, it is also quite likely that the vascular supply to these floral organs is also conservative and thus more reliable in taxonomic and phylogenetic interpretations (Fig. 8.11B).

The distribution and course of vascular bundles within the receptacle and floral parts have proved to be of systematic significance, particularly in ranking taxa of higher order such as genera and families. Even specific characters may be quite clear in some cases.

The significant role played by the floral anatomy in the solution of morphological problems has been greatly emphasized by Puri. Unlike other branches of anatomy, the application of floral anatomy to taxonomy is limited due to technical and interpretative difficulties.

However with the development of rapid clearing techniques, this branch of investigation received a great impetus. The floral anatomical characters of families and genera are generally well marked and have been useful in solving some fundamental questions, like the nature of flower, carpel, inferior ovary and also several problems related with homologies, phylogeny and taxonomy.

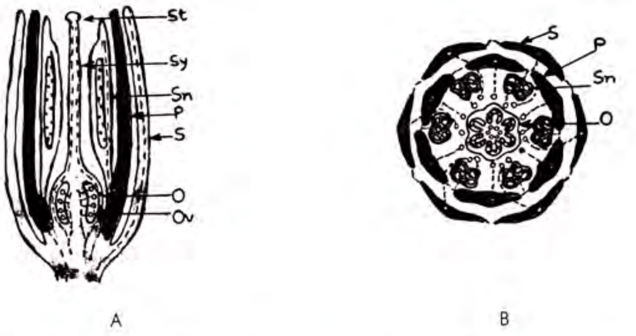


Fig. 8.11 : (A) Diagram of a flower in longitudinal section; (B) Same in cross-section ; broken lines are the course of vascular strands and their interconnections. S - Sepal, P - Petal, Sn– Stamen, St – Stigma, Sy - Style, O – Ovary, Ov - Ovules.

UNIT II:

Anatomical features of Root, Stem and Leaf of Dicot and Monocot. Normal and Anomalous secondary growth in Dicot stem- *Aristolochia, Nyctanthes* and Monocot stem- *Dracena*. Nodal anatomy- Types of nodes and origin of bud traces. Wood anatomy in relation to phylogeny.

Prepared By:

1. Dr. V. Latha,
2. Mrs. Tamil Selvi

Anatomical features of Root, Stem and Leaf of Dicot and Monocot

Dicotyledonous and Monocotyledonous Roots

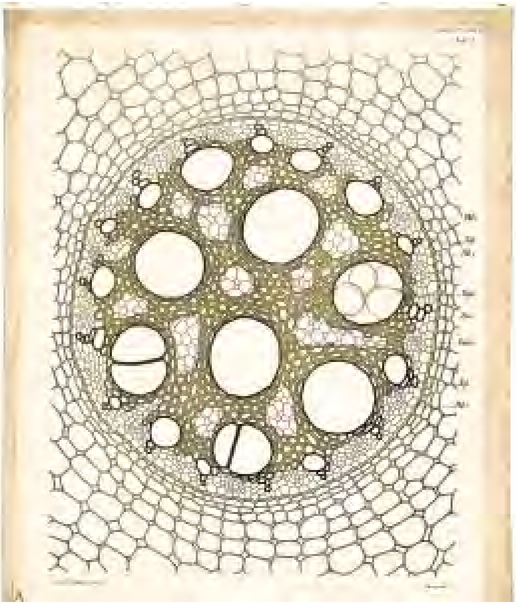
Dicot Root

- Dicot plants have the taproot system.
- The outermost layer is called the epidermis. The epidermal cells sometimes project out which appear as the root hairs.
- The epidermis is followed by the multi-layered cortex, loosely made of the parenchyma cells with intercellular spaces.
- The inner layer of the cortex is called endodermis, which is tightly packed by the barrel shaped-cells.
- Endodermis is followed by pericycle, which are a few layers of thick-walled parenchyma cells.
- In dicots, the central pith is not distinct.
- There are two to four xylem and phloem.
- The xylem and phloem are remarked by a layer of parenchymatous cells known as conjunctive tissue.

During secondary growth, the cambium separates the xylem and phloem. Pericycle, vascular bundles and pith fuse to form stele in dicots.

Monocot Root

Monocot roots do not show much difference in the anatomy from that of the dicot roots.



- Monocot plants possess an adventitious root system.
- As in the dicots, the epidermis forms the outermost layer, followed by cortex, pericycle, endodermis, vascular bundles (xylem and phloem) and pith (random order).
- Pith is conspicuous and large.
- The number of xylem in a monocot is six or more.
- Secondary growth is not seen in the monocot plants.

Dicotyledonous and Monocotyledonous Stem

Dicot Stem

The dicotyledonous stem is usually solid. The transverse section of a typical young dicotyledonous stem consists of the following parts:

- The epidermis is the outermost protective layer, which is covered with a thin layer of cuticle.

- Epidermis possesses trichomes and a few stomata.
- Cortex is multi-layered cells sandwiched between epidermis and pericycle.
- The outer layer, hypodermis (collenchymatous cells), the cortical layers (parenchymatous cells) and the inner layer, endodermis together make up the three subzones of the cortex.
- Next to endodermis is the pericycle, which is constituted of semi-lunar patches of sclerenchyma.
- ‘Circled’/ ‘ring’ arrangement of vascular bundles is present only in dicot stem.
- The Vascular bundle is conjoint, open and with endarch protoxylem.
- Pith is evident and is made of parenchymatous cells.

Monocot Stem

Monocot stem is usually hollow with no secondary growth. The anatomy of monocot and dicot stem are similar, however, some notable differences are as follows:

- The hypodermis of the cortex in monocots is made of sclerenchymatous cells.
- Vascular bundles are numerous, but scattered, conjoint and closed, surrounded by the ground tissue.
- Phloem parenchyma is absent.

Dicotyledonous and Monocotyledonous Leaves

Dicot Leaf

Dicotyledonous leaf shows reticulate venation.

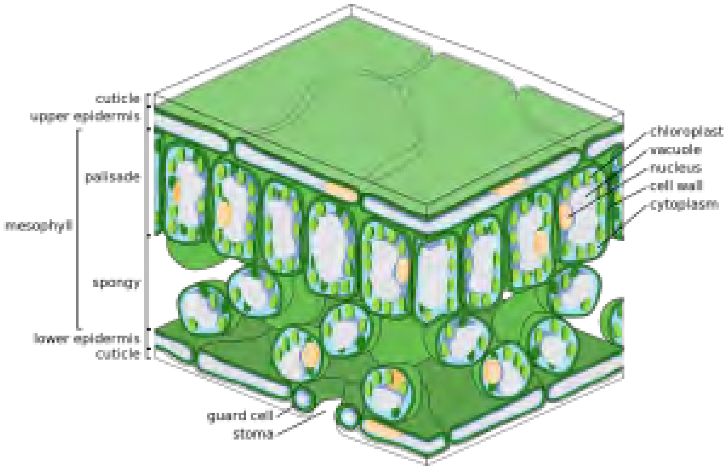
- Lamina consists of epidermis, mesophyll and vascular system.

- The epidermis is covered by cuticle and stomata; abaxial epidermis (lower surface) possesses more stomata than adaxial epidermis (upper surface). Sometimes adaxial epidermis lack stomata.

- Mesophyll, (parenchymatous cells) composed of the palisade and spongy parenchyma is present in between the adaxial epidermis and abaxial epidermis.

- The chloroplasts present in mesophyll perform photosynthesis in leaves.

- Vascular bundles are surrounded by bundle sheath cells and form the veins and midrib.



Monocot Leaf

Monocotyledonous leaves are characterized by parallel venation. The anatomy of a monocot leaf includes:

- Both adaxial epidermis and abaxial epidermis bear stomata.

- There is no differentiated palisade and spongy parenchyma of the mesophyll.

- Bulliform cells are present, which is developed from adaxial epidermal cells and the veins.

- Bulliform cells are large, void cells which are responsible for the curling of leaves for minimal loss of water.

Normal and Anomalous secondary growth in Dicot stem- *Aristolochia, Nyctanthes*

Secondary Growth in Aristolochia Stem (With Diagram)

It has been stated that this stem which is a liane, differs from the normal ones in the process of secondary growth.

The most striking points of difference are the formation of only parenchymatous medullary rays by the interfascicular cambium, and consequent occurrence of secondary tissues in strands (Fig. 641).

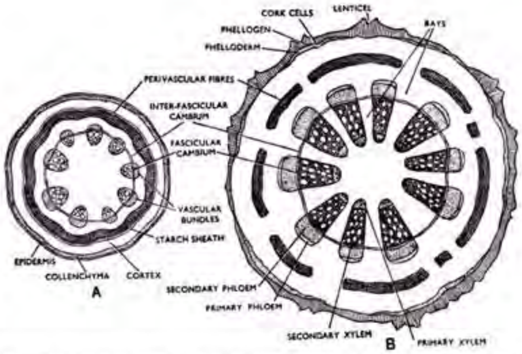


FIG. 641. *Aristolochia* stem in t.s. (diagrammatic). A. One-year old. B. Two-year old.

In the primary condition the Aristolochia stem has the following structure. Epidermis is uniseriate with cuticularised outer walls. Cortex is differentiated into collenchymatous hypodermis, parenchymatous portion and the starch sheath.

Chloroplasts are present in both collenchyma and parenchyma cells. A continuous band of sclerenchyma with strongly thickened walls occur. They may be called perivascular fibres, or may be said to form pericycle together with the adjoining parenchyma cells.

Broad medullary rays composed of parenchyma cells occur between the vascular bundles. The central portion of the stem is occupied by a large parenchymatous pith. The vascular bundles remain arranged in a ring. The bundles are distinctly collateral and open ones, with xylemand phloem on the inner and outer sides and having a strip of cambium in between the two.

With commencement of secondary growth in thickness a few parenchymatous cells of the broad medullary rays become meristematic in a line with the fascicular cambium of the vascular bundles. The newly-formed meristem, a secondary meristem, is known as interfascicular cambium.

It joins up with the fascicular cambium and thus a continuous cambium ring (Fig. 641 A) is formed. The fascicular cambium, in fact, the cambial zone goes on dividing tangentially and produces secondary xylem and secondary phloem on the inner and outer sides respectively.

Thus the primary xylem and primary phloem are pushed apart from each other. The secondary xylem has the usual elements arranged in vertical and horizontal systems. Metaxylem elements are fairly large in size. Annual rings with early wood and late wood are formed as a result of seasonal activities of the cambium.

The secondary phloem pushes the primary one on the outer side, and the latter usually gets crushed due to the pressure. Bands of sieve tubes and associated cells alternate with bands of parenchyma in the secondary phloem; fibres are absent. On the whole the vascular bundles increase enormously in size due to continued activity of the fascicular cambium.

The interfascicular cambium simply produces parenchyma cells on the outer and inner sides. Thus the medullary rays become increasingly more broad and long. The cells remain arranged in more or less radial rows.

The formation of the secondary tissues brings about profound changes in other portions of the stem. The central pith gets more and more reduced in extent. Distinct disruption in the continuous cylinder of sclerenchyma is caused by the increase, so that the band is ruptured here and there, commonly in front of the medullary rays.

The adjoining parenchyma cells fill up the gaps thus formed. These cells gradually undergo sclerosis and are ultimately transformed into sclereids. They, in fact, repair, so to say, the gaps caused by the onrush of the internal tissues.

The band of hypodermal collenchyma also suffers from pressure and breaks down frequently. The parenchyma cells of the cortex make their way into the breaks and thus occur as strips amongst hypodermal collenchyma.

The epidermis gets stretched and ruptures. Periderm develops in the subepidermal layers. Phellogen is formed in patches. They divide and produce a thick layer of cork cells on the outer side and considerable phelloderm on the inner. Lenticels are formed.

Secondary Growth in *Nyctanthes* Stem

Epidermis

♣ Single-layered epidermis consists of rectangular cells.

♣ A thick uninterrupted cuticle is present on the epidermis.

♣ Many multicellular hairs are present.

Cortex

♣ It is differentiated into collenchyma and parenchyma.

♣ Collenchyma is several cells deep below the four protruded comers while only few layers deep at the other places just beneath the epidermis.

♣ Parenchyma is present below the collenchyma. Many intercellular spaces are present. The region extends up to the vascular tissue.

Cortical bundles

♣ Four vascular bundles are present in the cortex, situated one each in each protruded bulge.

♣ Each conical bundle faces its pointed xylem end towards outer side, i.e., epidermis, and is conjoint, collateral, open and exarch.

♣ These bundles may show secondary growth at maturity.

Endodermis

♣ Not well-developed. Pericycle

♣ It is in the form of sclerenchymatous patches.

Vascular System

♣ It consists of primary phloem, secondary phloem, cambium, secondary xylem and primary xylem.

♣ Primary phloem is crushed and irregularly present in patches below pericycle.

♣ Secondary phloem is present in the form of a continuous ring and consists of sieve tubes, companion cells and phloem parenchyma.

♣ Cambium is one to three cells thick continuous layer present in between phloem and xylem.

♣ Secondary xylem is present just inner to the cambial ring and consists mainly of thick walled wood parenchyma and fibres. Tracheids and vessels are also present.

♣ Primary xylem is situated just near the pith facing its protoxylem towards the centre.

Pith

♣ It is thin walled and parenchymatous.

Abnormality

♣ Abnormal secondary growth in Nyctanthes is due to abnormality in primary structure due to presence of medullary or cortical bundles.

♣ These cortical bundles are actually leaf trace bundles. Secondary growth in medullary vascular bundles of Nyctanthes is of normal type which takes place through a typical cambial ring formation while cortical bundles present in four corners of the stem.

♣ More of secondary xylem is formed on the outer side and less of the secondary phloem towards inner side.

♣ Due to more tissue differentiation towards outside distinct ridges would be formed at the four sides of Nyctanthes stem.

Secondary Growth in *Dracena*- Monocot Stem:

The vascular bundles of the monocotyledonous stems are usually closed ones. Thus due to absence of the cambium, they lack secondary growth in thickness and the vascular system is wholly composed of primary tissues.

The bundles remain irregularly scattered in the ground tissues, forming an atactostele, where the limits of cortex and other ground tissues can be hardly discerned.

Some monocotyledons belonging to the family Liliaceae, such as Dracaena, Yucca, Agave, Aloe and others exhibit a peculiar type of secondary growth in thickness, that may be called anomalous because of unusual phenomenon.

Dracaena is a typical example of anomalous secondary thickening (growth) in monocots.

Dracaena Stem :-

The young stem of Dracaena is typical monocot stem . The cross-section of Dracaena stem shows the following structure .

Epidermis - Outer most single layer consist of parenchymatous cells remains covered with thick cuticle. The lenticels are also visible on the epidermis.

Hypodermis - Situated just below the epidermis composed of sclerenchymatous cells.

Ground Tissue - Ground tissues is undifferentiated parenchymatous. It is not divisible into cortex and pith due to absence of endodermis and pericycle.

Vascular Bundles - Several amphivasal closed vascular bundles lie scattered on the ground.

Anomalous Secondary Thickening In Dracaena –

In Dracaena secondary growth is due to –

a) Extrastelar cambial ring in a monocots stem at the cortex.

b) Abnormal activity of cambium.

During Secondary Thickening –

Dracaena shows anomalous secondary growth. The cambium appears in the parenchyma outside the outermost vascular bundles. In the regions which have ceased to elongate some cells occurring outside the vascular bundles become meristematic and form the cambium. The secondary meristem originates in the cortex, in fact, deep layers of cortex or pericycle. Here the meristem will be named as secondary thickening meristem (STM). e. The activity of the cambium is abnormal. Instead of forming phloem and xylem on the outer and inner sides, as in normal condition, the cambial ring producing large number of secondary tissues to the inner side first, and later small amount of new tissues are cut off on the outer side as well.

The tissues cut off by the cambial cells on the outer side are scanty in amount and are parenchymatous in nature. The tissues those produced on the inner side of the cambium are partially parenchymatous and partially vascular in nature.

The parenchymatous cells produced internally to the cambium developed into lignified conjunctive tissue. The radial arrangement of the parenchyma cells of conjunctive tissue is due to their origin by tangential divisions of the cambial cells. So they may be easily distinguished from the irregularly arranged parenchyma of the primary ground tissues.

Usually, the secondary vascular bundles arise from a single cell called vascular bundle initial. The vascular bundle initial cell divide by two anticlinal division to form a row of two or three cells. All these cells then undergo a periclinal division to form peripheral cells. Later divisions are irregular and form a mass of cells. In this mass of cells, the centrally placed cell metamorphoses into phloem cells. The peripheral cells differentiated into xylem. Thus, the newly formed secondary vascular bundles consists of a centrally placed phloem which is surrounded by the xylem (amphivasal type).

The secondary vascular bundles are amphivasal. Secondary vascular bundles are differ from the primary ones in presence of small amount of phloem and in absence of annular and spiral protoxylem elements. The small amount of phloem consists of short sieve tubes and companion cells and parenchyma. The Xylem is made of only tracheids, usually with scalariform thickening and small amount of xylem parenchyma which have lignified walls.

The cambium then cut parenchyma cells internally. The newly formed parenchyma cells push the vascular bundles towards the central region.

After some time the cambium again behave abnormally to produce another ring of vascular bundles. This process continues and many rings of concentrically arranged vascular bundles are formed. The last ring of vascular bundles is embedded in a mass of lignified conjunctive tissue.

In the extrastelar region the periderm is formed because of the repeated periclinal divisions of the cortical cells. Here the cork cells, formed without the appearance of cork cambium, are called storied-cork.

Nodal anatomy- Types of nodes and origin of bud traces

In dicotyledon the vascular bundles are usually more or less in a ring and show different arrangements at the nodes and internodes. The vascular cylinders are generally continuous at the internode and their continuity is interrupted at the nodal region due to the emergence of bundles that terminate either at the leaf bases, axillary buds or stipules etc.

At the node three types of bundles are recognized:

(i) Leaf trace bundle:

The single vascular bundle that connects the leaf base with the main vascular cylinder of stem is designated as leaf trace bundle. In a leaf there may be several leaf trace bundles that collectively are termed as leaf traces.

(ii) Cauline bundle:

The vascular bundles that entirely form the vascular system of stems are known as cauline bundles. Sometimes these bundles anastomose with each other and extend from stem to leaf as leaf traces.

(iii) Common bundle:

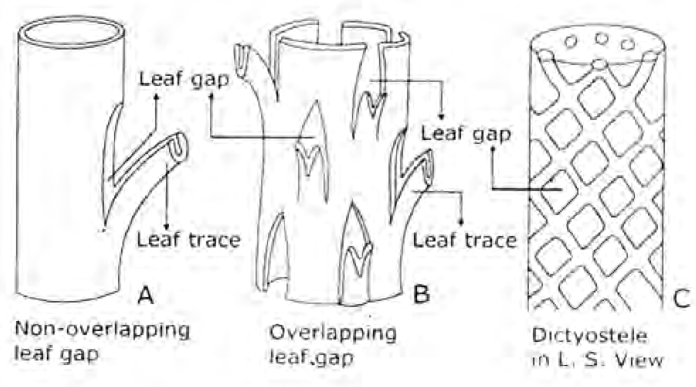
The vascular bundles, which run unbranched through a few successive nodes and internodes and ultimately terminate as leaf traces are called common bundles.

The arrangement of vascular tissues at the nodes is more complex than the internodes due to emergence of vascular traces to the leaves, buds, stipules etc., present at the node.

i. Leaf trace and leaf gap (Fig. 17.1A, B & C):

A leaf trace is defined as the cauline part of vascular tissue that departs from the stele of stem towards leaf base. Leaf trace may be a portion of cauline bundle as it occurs within the caulis, that is, stem. Cauline bundles entirely form the vascular system of stems.

Sometimes cauline bundle departs from the stele towards leaf base thus forming leaf trace. Leaf trace is seen in the nodal region of stem. Leaf trace is an independent bundle that may occur through one or more nodes and internodes before bending away from the stem toward the leaf.



Non-overlapping leaf gap

Overlapping leaf.gap

Dictyostele in L. S. View

Figure 17.1

Diagrammatic illustration in three dimensional view of vascular cylinder at node with leaf gap (A & B) and dictyostele (C). A & B are redrawn after Sporne

A leaf trace originates from the apical meristem of leaf primordium. After complete differentiation it joins with the vascular tissue of stem. Apart from leaf trace other vascular strands entirely occur in the stem. They constitute the cauline (= stem) bundle. They originate from apical meristem of shoot apex. Some cauline bundles may bend towards leaf thus forming leaf trace and these bundles are referred to as common bundles.

In the nodal region, a leaf trace bends away from the vascular cylinder of stem toward the petiole of leaf. From the base of petiole leaf trace extends into leaf blade where the trace forms vascular bundle of leaf. In the stem phloem occurs on the peripheral side of vascular cylinder.

As the leaf trace is bent away from the vascular cylinder toward petiole phloem in the vascular bundle of leaf occurs on the abaxial side of leaf (Fig. 17.2A). As a result the vascular bundle of leaf has an inverted orientation of xylem and phloem in relation to vascular bundle of stem.

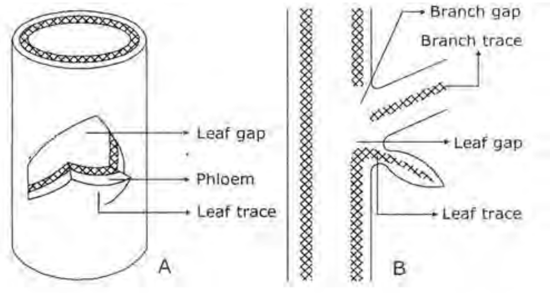


Figure 17.2

A. Diagram illustrating the position of phloem when a leaf trace enters to leaf base. B. Diagram showing the positions of leaf gap and branch gap in longitudinal sectional view of stem at node. Xylem crosshatched.

A cross-section through node reveals that, there is a break in the vascular cylinder of stem, that is, the vascular cylinder is not in the form of a continuous ring. In this region the vascular tissue is interrupted and parenchyma cells fill the gap. Pith and cortex are continuous through this gap (Fig. 17.6).

Such region is referred to as leaf gap and occurs opposite to leaf trace. A leaf gap is defined as the wide interfascicular region that is located opposite the upper part of leaf trace and is filled up with parenchyma cells through which pith and cortex become continuous.

There exist many variations in the number of leaf gaps and the number of leaf traces in different plants. The variation may be different in the same plant at different levels, e.g. Hypecoum procumbens—the lower node of which has three traces per leaf whereas the upper nodes have single trace per leaf. The variations are subjects of comparative studies and therefore have taxonomic and phylogenetic significance.

Atactostele is the characteristic of monocot stem and the arrangement of vascular strands at the node is highly complex. Comparatively the anatomy at the node of dicotyledonous stem is less complex. To describe the nodal anatomy of stem different terms are used.

In the terminology the term lacuna replaces the term gap. Dicotyledonous nodes are very suitable to study the nodal anatomy and the different terminology used to describe the anatomy of nodes is chiefly based on dicotyledons.

The following types of anatomy at nodes in dicots are recognized:

(a) Unilacunar single-trace node:

This type of node exhibits one leaf trace to a leaf and the leaf trace is associated with one lacuna. Ex. Spiraea. Unilacunar nodes are exstipulate (Figs. 17.3 & 17.4A).

(b) Unilacunar two-trace node:

This type of node has two leaf traces to a single leaf and one lacuna. The two leaf traces are associated with the single lacuna. Ex. Clerodendron (Fig. 17.3).

(c) Trilacunar node:

This type of node has three leaf traces to a leaf and three lacunae. Each trace is associated with single lacuna (Fig. 17.4B). Ex. Salix. Among the three traces, the trace that occurs in the median position with reference to leaf is referred to as median trace. The others are called lateral traces. This type of node has stipules.

(d) Multilacunar node:

This type of node has more than three traces to a leaf and more than three lacunas. Each trace is confronted with single lacuna. Ex. Rumex. Multilacunar node is exhibited in the plants that have sheathing leaf bases.

It is to note that the terms unilacunar-, trilacunar- and multilacunar node are applied with reference to a single leaf. In this sense in unilacunar node each leaf is associated with one lacuna. A node may consist more than one leaf. A cross-section of such node reveals the presence of more than one lacuna and more than one leaf trace.

Such node is to be referred in relation to the number of lacuna(s) associated to a single leaf, that is, in trilacunar node one leaf is associated with three lacunas and in multilacunar node one leaf is associated with several lacunas. In other words, whatever may be the number of leaves present, a node is characterized with reference to the number of lacuna(s) present in a single leaf.

In unilacunar node a leaf has one trace, in trilacunar node three traces diverse to a single leaf and in multilacunar node several traces are present in a single leaf. Usually one gap is associated with one trace but in two-trace unilacunar condition two leaf traces confront to a single gap and in three-trace unilacunar condition three leaf traces are associated to a single gap (Figs. 17.3 & 17.4C).

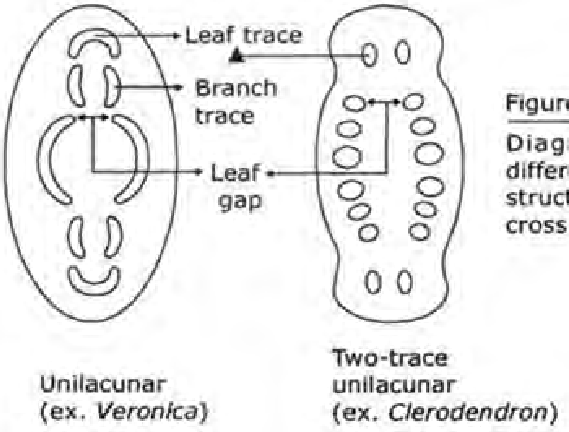


Figure 17.3

Diagram illustrating different types of nodal structures as seen in cross sections of stems.

It is mentioned previously that a leaf gap is identifiable at the node. In internode also leaf gaps may be identified when a leaf trace has oblique course through a part of the internode. Studies on the cross-section of internode, if followed level by level, will reveal position(s) of leaf gap(s) and the continuity between ground tissue and pith.

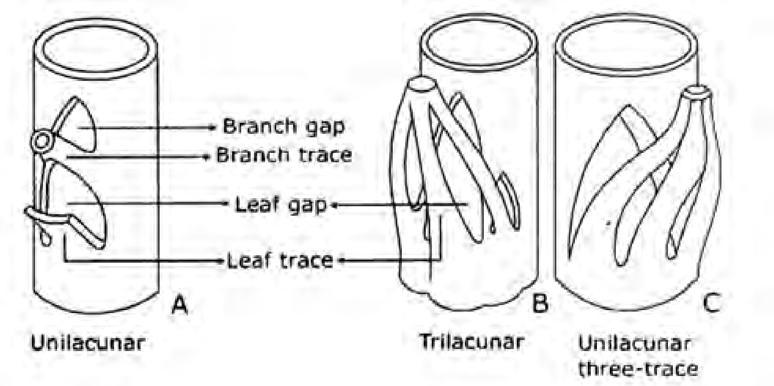


Figure 17.4

Diagram illustrating in three dimensional view of leaf trace, leaf gap, branch trace and branch gap. A & B are redrawn after Esau and C is redrawn after Fahn

A definite nodal type generally characterizes a taxon. Unilacunar node is found in Centrospermae and in certain members of Myrtaceae (Eucalyptus), Lauraceae (Laurus) etc. Trilacunar node occurs in Compositae (Chrysanthemum), Salicaceae (Salix), Brassicaceae (Brassica) etc. Multilacunar node is observed in Polygonaceae (Rumex) etc.

The anatomy of the node is regarded an important aspect in the study of phylogeny in dicotyledons, since a definite nodal type characterizes a taxon. According to Sinnott (1914) trilacunar node is primitive among dicotyledons. During evolution it gave rise to unilacunar type by reduction in the number of gaps and traces.

Reduction occurred either by the disappearance of the two lateral gaps with the associated two lateral traces or the two lateral traces became confluent with the median trace. In the latter case a single bundle is formed consisting of three traces. This bundle is associated with a single gap to form unilacunar node.

Trilacunar condition also gave rise to multilacunar type by the formation of more new gaps and traces. Though unilacunar condition is considered as advanced, later studies on nodal anatomy by Bailey (1956), Fahn and Bailey (1957) and others reveal that unilacunar condition is primitive as this type is found in some primitive groups like pteridophyta, fossil gymnosperms like Bennettitales and Cordaitales, Ginkgo and Ephedra.

Unilacunar two-trace node also seems to be primitive as it is represented by extinct Cordaitales and Bennettitales, and extant ferns, conifers, Ephedra and the primitive dicotyledonous genus Austrobaileya etc.

Trilacunar node is widespread and is exhibited in the families like Winteraceae, Meliaceae, Rosaceae and Asteraceae etc. Degeneriaceae and Chenopodiaceae etc. exhibit multilacunar condition. Lepidium latifolium has unilacunar node with several leaf traces. It is regarded as more primitive than the unilacunar one-trace node.

Previously the nodal structures were described on the basis of number of leaf traces that are associated with each leaf, e.g. one-trace, two-trace, three-trace and multi-trace.

Later the nodal anatomy is interpreted on the basis of leaf gaps that are associated with each leaf, e.g. unilacunar, trilacunar and multilacunar. Still later leaf gap and leaf trace —these two aspects were combined to describe a node, e.g. unilacunar-one trace, unilacunar-two trace etc.

Before the discovery of unilacunar two-trace node, trilacunar node was regarded as central type from which unilacunar and multilacunar node arose. It is interpreted that unilacunar node is more advanced than trilacunar node.

Later in the light of above facts it is now interpreted that the evolution of nodal structure proceeded in the following two sequences:
(i) Two trace unilacunar gave rise to trilacunar, which terminated in multilacunar condition;

(ii) Two-trace unilacunar, by the loss of one trace, gave rise to one trace unilacunar that formed trilacunar node by the addition of two new gaps associated with two traces.

The multilacunar condition is derived from the trilacunar type by the addition of more new traces and gaps (Fig.17.5). This evolutionary sequence may be observed in a single family namely Chenopodiaceae. The trilacunar type may also give rise to one trace unilacunar condition.

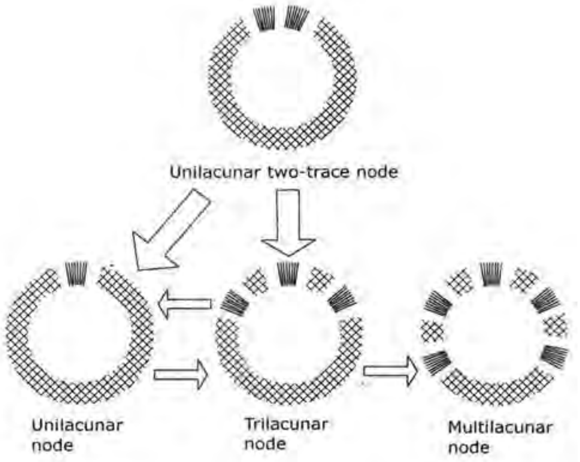


Figure 17.5

Diagrams illustrating the probable lines of development of nodal vascularization. Xylem crosshatched. ▥ = leaf trace.

ii. Branch trace and branch gap:

Branch trace can be defined as the vascular trace that originates from the vascular cylinder of stem and enters to a branch. The position of the origin of a branch is from the axil of a leaf (Fig. 17.4A). In this position the vascular cylinder of stem is discontinuous. Parenchyma occupies this region as observed in a cross-section of stem at node.

This interrupted region of vascular cylinder due to the presence of branch trace is designated as branch gap. Two branch traces are associated to a single leaf gap. Branch trace directly diverges to a branch from the main vascular cylinder of stem without running obliquely through the internode.

The branch traces depart from the main vascular cylinder of stem toward right and left of the median leaf trace. After a short distance the traces coalesce and form a complete stele similar to main vascular cylinder. So the vascular bundle of branch has the same orientation of xylem and phloem in relation to the vascular bundle of stem.

It is previously mentioned that branch develops from axillary bud that originates on the stem at the axil of leaves. From the time of initiation the buds are connected by vascular traces to the vascular strands on the main axis. These vascular traces are referred to as bud trace or branch trace or ramular trace.

Axillary buds form axillary shoots whose first foliar structures are the prophylls. In dicotyledons, usually two branch traces emerge out from the vascular cylinder of stem. In exceptional cases the branch trace may be one (e.g. Peperomia, Cayratia etc.) or more than two. Sometimes medullary bundles may enter into the bud (Ex. Dahlia).

In case of single branch supply the vascular cylinder appears as crescent or horseshoe shaped in cross sectional view with the opening downward. After a short distance the opening closes and the cylindrical stele of the branch is formed. When the branch traces are more than one they coalesce after a short distance, forming a complete stele similar to that of the main axis.

In dicotyledons there occurs two prophylls, which are oriented in such a way that their plane of bisection is parallel with the plane of the axillant leaf. Initially two branch traces supply the prophylls. The branch traces are composed of one or more bundles that later increase in size due to the formation of vascular traces to the other leaves of the branch, situated above. Thus the branch traces, are actually the leaf traces of the axillary shoot.

The continuity of the vascular cylinder of stem is interrupted at the nodal region due to the emergence of branch traces. At this region and above the point of departure parenchyma differentiates instead of vascular tissues. The parenchymatous area in the vascular cylinder of stem at the node immediately above the branch trace is the branch gap through which pith and cortex become continuous.

Branch gap occurs in those vascular plants, which have pith. In pteridophytes, where the vascular cylinder is protostele and devoid of pith, branch gap is absent. So the branch gap in association with leaf gap results in the formation dissected siphonostele.

There exists a definite correlation between leaf—and branch trace. As seen in cross-section of a stem at node a leaf trace occurs on the peripheral side. It is followed by branch trace towards the inner side (Fig. 17.3). A node that bears a single leaf exhibits the following sequences from periphery towards centre —leaf trace, branch trace and leaf gap on the side where the leaf is inserted.

When there are two leaves in each node the above mentioned sequences of leaf—and branch trace and leaf gap are observed on the opposite sides in a cross-section of stem at node. In longitudinal section the positions of branch gap and leaf gap (Fig. 17.2B), and their relation can be observed individually.

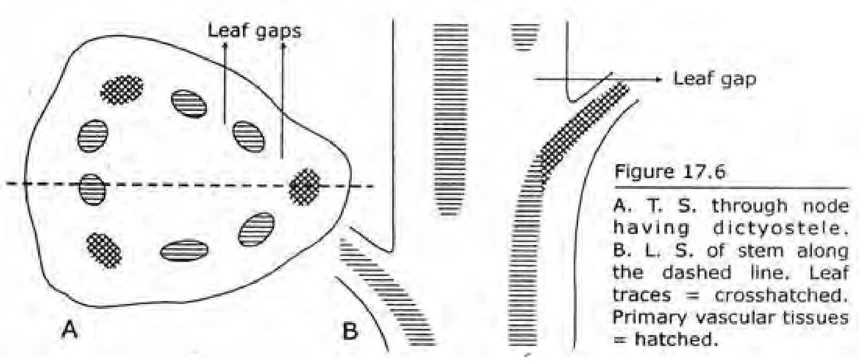


Figure 17.6

A. T. S. through node having dictyostele. B. L. S. of stem along the dashed line. Leaf traces = crosshatched. Primary vascular tissues = hatched.

UNIT III: EMBRYOLOGY

Microsporogenesis- Structure and development of Microsprorangium- development of Male gametophyte, Megasporogenesis- Structure and development of Megasporangium- Types of ovule, Development of female gametophyte. Fertilization, Development of Dicot and Monocot Embryo.

Prepared By:

1. Dr. V. Latha,
2. Dr. K. Tamil Selvi

Microsporogenesis and Megasporogenesis

Sexual reproduction takes place with slight variations in different groups of plants. Plants have two distinct stages in their lifecycle: the gametophyte stage and the sporophyte stage. The haploid **gametophyte** produces the male and female gametes by mitosis in distinct multicellular structures. Fusion of the male and females gametes forms the diploid zygote, which develops into the **sporophyte**. After reaching maturity, the diploid sporophyte produces spores by meiosis, which in turn divide by mitosis to produce the haploid gametophyte. The new gametophyte produces gametes, and the cycle continues. This is the alternation of generations, and is typical of plantreproduction.

The life cycle of higher plants is dominated by the sporophyte stage, with the gametophyte borne on the sporophyte. In ferns, the gametophyte is free-living and very distinct in structure from the diploid sporophyte. In bryophytes, such as mosses, the haploid gametophyte is more developed than the sporophyte.

During the vegetative phase of growth, plants increase in size and produce a shoot system and a root system. As they enter the reproductive phase, some of the branches start to bear flowers. Many flowers are borne singly, whereas some are borne in clusters. The flower is borne on a stalk known as a receptacle. Flower shape, color, and size are unique to each species, and are often used by taxonomists to classify plants.

Sexual Reproduction in Angiosperms

The lifecycle of angiosperms follows the alternation of generations explained previously. The haploid gametophyte alternates with the diploid sporophyte during the sexual reproduction process of angiosperms. Flowers contain the plant’s reproductive structures.

Flower Structure

A typical flower has four main parts—or whorls—known as the calyx, corolla, androecium, and gynoecium (Figure 2). The outermost whorl of the flower has green, leafy structures known as sepals. The sepals, collectively called the calyx, help to protect the unopened bud. The second whorl is comprised of petals—usually, brightly colored—collectively called the corolla. The number of sepals and petals varies depending on whether the plant is a monocot or dicot. In monocots, petals usually number three or multiples of three; in dicots, the number of petals is four or five, or multiples of four and five. Together, the calyx and corolla are known as the perianth.

The third whorl contains the male reproductive structures and is known as the androecium. The **androecium** has stamens with anthers that contain the microsporangia. The innermost group of structures in the flower is the **gynoecium**, or the female reproductive component(s). The carpel is the individual unit of the gynoecium and has a stigma, style, and ovary. A flower may have one or multiple carpels.

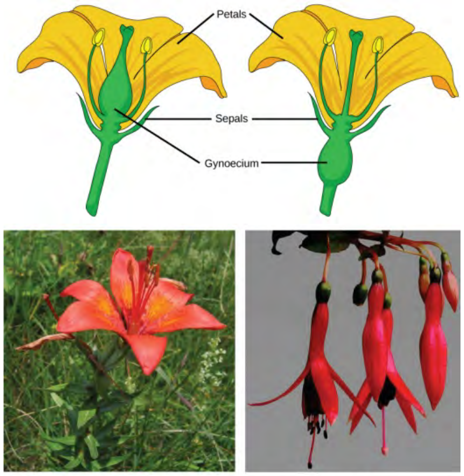
If the anther is missing, what type of reproductive structure will the flower be unable to produce? What term is used to describe an incomplete flower lacking the androecium? What term describes an incomplete flower lacking a gynoecium? Pollen (or sperm); carpellate; staminate.

If all four whorls (the calyx, corolla, androecium, and gynoecium) are present, the flower is described as complete. If any of the four parts is missing, the flower is known as incomplete. Flowers that contain both an androecium and a gynoecium are called perfect, androgynous or hermaphrodites. There are two types of incomplete flowers: staminate flowers contain only an androecium, and carpellate flowers have only a gynoecium (Figure 3).

Figure 3. The corn plant has both staminate (male) and carpellate (female) flowers.

Staminate flowers, which are clustered in the tassel at the tip of the stem, produce pollen grains. Carpellate flower are clustered in the immature ears. Each strand of silk is a stigma. The corn kernels are seeds that develop on the ear after fertilization. Also shown is the lower stem and root.

If both male and female flowers are borne on the same plant, the species is called monoecious (meaning "one home"): examples are corn and pea. Species with male and female flowers borne on separate plants are termed dioecious, or "two homes," examples of which are *C. papaya* and *Cannabis*. The ovary, which may contain one or multiple ovules, may be placed above other flower parts, which is referred to as superior; or, it may be placed below the other flower parts, referred to as inferior (Figure 4).



(a) Superior flower

(b) Inferior flower

Figure 4. The (a) lily is a superior flower, which has the ovary above the other flower parts. (b) Fuchsia is an inferior flower, which has the ovary beneath other flower parts. (credit a photo: modification of work by Benjamin Zwittnig; credit b photo: modification of work by "Koshy Koshy"/Flickr)

Male Gametophyte (The Pollen Grain)

The male gametophyte develops and reaches maturity in an immature anther. In a plant's male reproductive organs, development of pollen takes place in a structure known as the **microsporangium** (Figure 5). The microsporangia, which are usually bi-lobed, are pollen sacs in which the microspores develop into pollen grains. These are found in the anther, which is at the end of the stamen—the long filament that supports the anther.

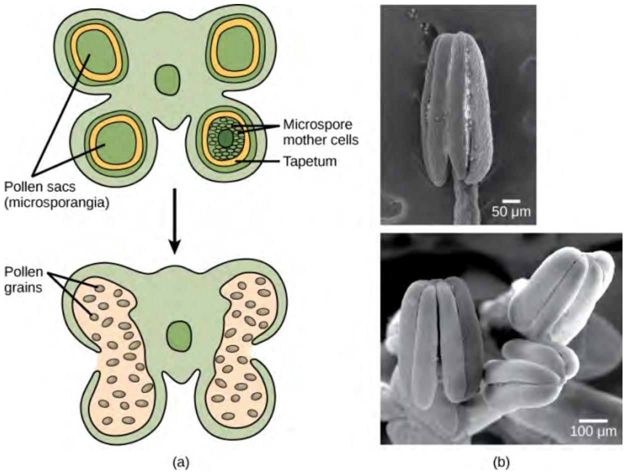


Figure 5. Shown is (a) a cross section of an anther at two developmental stages. The immature anther (top) contains four microsporangia, or pollen sacs. Each microsporangium contains hundreds of microspore mother cells that will each give rise to four pollen grains. The tapetum supports the development and maturation of the pollen grains. Upon maturation of the pollen (bottom), the pollen sac walls split open and the pollen grains (male gametophytes) are released. (b) In these scanning electron micrographs, pollen sacs are ready to burst, releasing their grains. (credit b: modification of work by Robert R. Wise; scale-bar data from Matt Russell)

Within the microsporangium, the microspore mother cell divides by meiosis to give rise to four microspores, each of which will ultimately form a pollen grain (Figure 6). An inner layer of cells, known as the tapetum, provides nutrition to the developing microspores and contributes key components to the pollen wall. Mature pollen grains contain two cells: a generative cell and a pollen tube cell. The generative cell is contained within the larger pollen tube cell. Upon germination, the tube cell forms the pollen tube through which the generative cell migrates to enter the ovary. During its transit inside the pollen tube, the generative cell divides to form two male gametes (sperm cells). Upon maturity, the microsporangia burst, releasing the pollen grains from the anther.

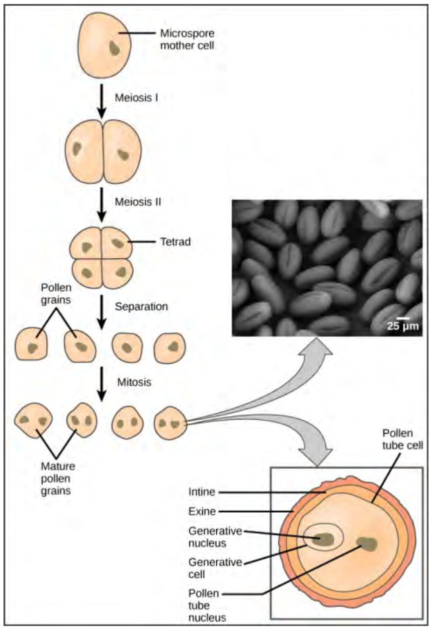


Figure 6. Pollen develops from the microspore mother cells. The mature pollen grain is composed of two cells: the pollen tube cell and the generative cell, which is inside the tube cell. The pollen grain has two coverings: an inner layer (intine) and an outer layer (exine). The inset scanning electron micrograph shows Arabidopsis lyrata pollen grains. (credit “pollen micrograph”: modification of work by Robert R. Wise; scale-bar data from Matt Russell)

Each pollen grain has two coverings: the **exine** (thicker, outer layer) and the **intine** (Figure 6). The exine contains sporopollenin, a complex waterproofing substance supplied by the tapetal cells. Sporopollenin allows the pollen to survive under unfavorable conditions and to be carried by wind, water, or biological agents without undergoing damage.

Female Gametophyte (The Embryo Sac)

While the details may vary between species, the overall development of the female gametophyte has two distinct phases. First, in the process of **megasporogenesis**, a single cell in the diploid **megasporangium**—an area of tissue in the ovules—undergoes meiosis to produce four megaspores, only one of which survives. During the second phase, **megagametogenesis**, the surviving haploid megaspore undergoes mitosis to produce an eight-nucleate, seven-cell female gametophyte, also known as the megagametophyte or embryo sac. Two of the nuclei—the **polar nuclei**—move to the equator and fuse, forming a single, diploid central cell. This central cell later fuses with a sperm to form the triploid endosperm. Three nuclei position themselves on the end of the embryo sac opposite the micropyle and develop into the **antipodal** cells, which later degenerate. The nucleus closest to the micropyle becomes the female gamete, or egg cell, and the two adjacent nuclei develop into **synergid** cells (Figure 7). The synergids help guide the pollen tube for successful fertilization, after which they disintegrate. Once fertilization is complete, the resulting diploid zygote develops into the embryo, and the fertilized ovule forms the other tissues of the seed.

A double-layered integument protects the megasporangium and, later, the embryo sac. The integument will develop into the seed coat after fertilization and protect the entire seed. The ovule wall will become part of the fruit. The integuments, while protecting the megasporangium, do not enclose it completely, but leave an opening called the **micropyle**. The micropyle allows the pollen tube to enter the female gametophyte for fertilization.

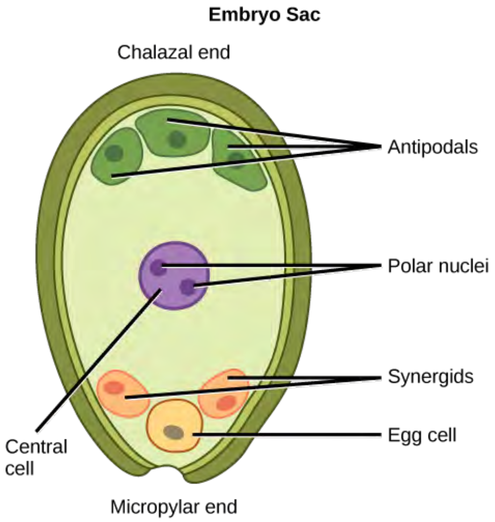


Figure 7. As shown in this diagram of the embryo sac in angiosperms, the ovule is covered by integuments and has an opening called a micropyle. Inside the embryo sac are three antipodal cells, two synergids, a central cell, and the egg cell.

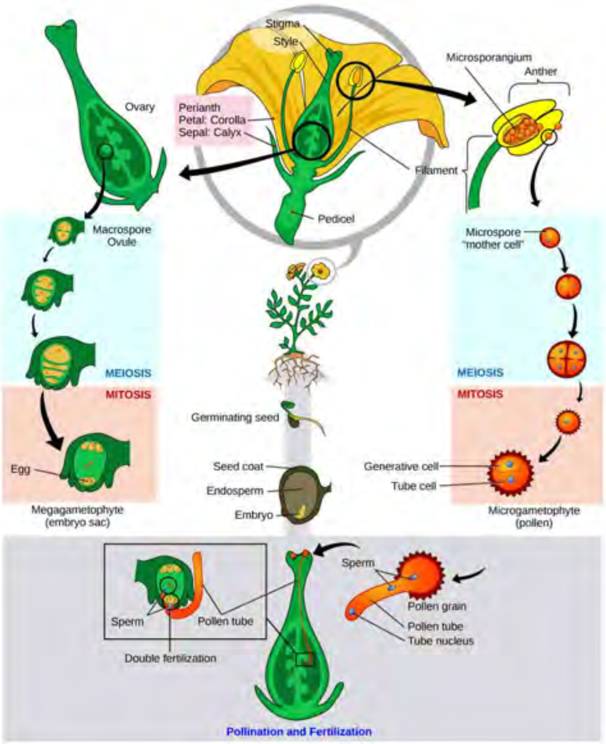
An embryo sac is missing the synergids. What specific impact would you expect this to have on fertilization?

1. The pollen tube will be unable to form.
2. The pollen tube will form but will not be guided toward the egg.
3. Fertilization will not occur because the synergid is the egg.
4. Fertilization will occur but the embryo will not be able to grow.

Development of Dicot and Monocot Embryo

Read this article to learn about the structure, types and development of the embryo in flowering plants

Embryogeny is the sum total of changes that occur during the development of a mature embryo from a zygote or oospore.



(a) Embryogeny in Dicots:

In a typical dicot (Fig. 2.30) the zygote elongates and then divides by a transverse wall into two unequal cells (Schulz and Jensen, 1969).

The larger basal cell is called suspensor cell. The other towards the antipodal end is termed as terminal cell or embryo cell. The suspensor cell divides transversely a few times to produce a filamentous suspensor of 6-10 cells. The suspensor helps in pushing the embryo in the endosperm.

The first cell of the suspensor towards the micropylar end becomes swollen and functions as a haustorium. The haustorium has wall ingrowths similar to transfer cells (Schulz and Jensen, 1969). The last cell of the suspensor at the end adjacent to the embryo is known as hypophysis. Hypophysis later gives rise to the radicle and root cap.

The embryo cell undergoes two vertical divisions (quadrant stage) and one transverse division to form eight cells arranged in two tiers (octant stage) epibasal (terminal) and hypobasal (near the suspensor). The epibasal cells eventually form the two cotyledons and the plumule. The hypobasal cells produce the hypocotyl except its tip.

The eight embryonic cells or octants divide periclinally to produce an outer layer of protoderm or dermatogen. The inner cells differentiate further into procambium (= plerome) and ground meristem (= periblem). Protoderm forms epidermis, procambium gives rise to steal or vascular strand and ground meristem produces cortex and pith.

Initially the embryo is globular and undifferentiated. Early embryo with radial symmetry is called proembryo. It is transformed into embryo with the development of radicle, plumule and cotyledons.

Two cotyledons differentiate from the sides with a faint plumule in the centre. At this time the embryo becomes heart-shaped. The rate of growth of the cotyledons is very high so that they elongate tremendously while the plumule remains as a small mound of undifferentiated tissue.

Structure of Dicot Embryo:

A typical dicotyledonous embryo (Fig. 2.30 H) consists of an embryonal axis and two cotyledons. The part of embryonal axis above the level of cotyledons is called epicotyl. It terminates with the stem tip, called plumule (future shoot). The part below the level of cotyledons is called hypocotyl which terminates in the root tip called radicle (future root). The root tip is covered with a root cap (calyptra).

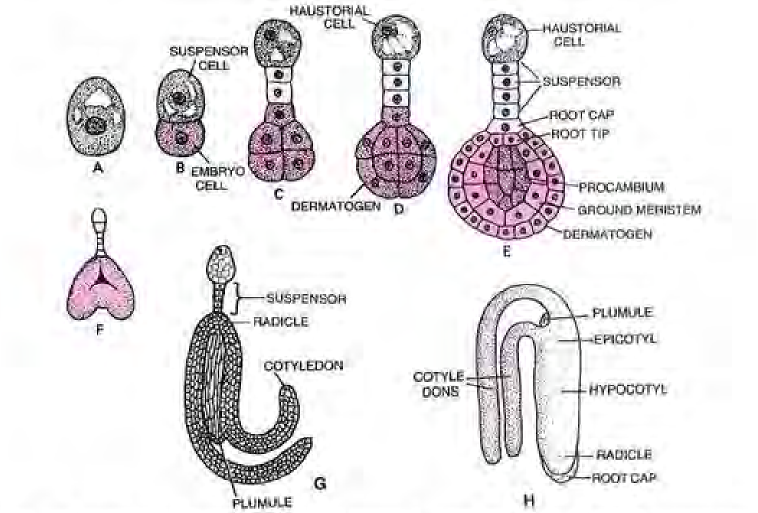


Fig. 2.30. Stages in the development of a dicot embryo. A, Zygote or oospore. B, Division of zygote into suspensor and embryo cells. C, Formation of suspensor and embryo octant. D, Periclinal divisions of embryo octants to form outer dermatogen. E, Globular embryo showing regions of radicle, procambium, ground meristem and dermatogen. F, Heart-shaped embryo. G, Mature dicotyledonous embryo. H, a typical dicot embryo.

In Capsella bursa-pastoris, the elongating cotyledons curve due to the curving of the ovule itself. With the growth of embryo, the ovule enlarges. Its integuments ultimately become hard to form protective coverings.

Now the embryo undergoes rest and the ovule gets transformed into seed. In some plants the embryo remains in the globular or spherical form even at the time of seed shedding without showing any distinction of plumule, radicle and cotyledons, e.g., Orobanche, Orchids, Utricularia.

(b) Embryogeny in Monocots:

The zygote or oospore elongates and then divides transversely to form basal and terminal cells. The basal cell (towards micropylar end) produces a large swollen, vesicular suspensor cell. It may function as haustorium. The terminal cell divides by another transverse wall to form two cells.

The top cell after a series of divisions forms plumule and a single cotyledon. Cotyledon called scutellum, grows rapidly and pushes the terminal plumule to one side. The plumule comes to lie in a depression.

The middle cell, after many divisions forms hypocotyl and radicle. It also adds a few cells to the suspensor. In some cereals both plumule and radicle get covered by sheaths developed from scutellum called coleoptile and coleorhiza respectively.

Structure of Monocot Embryo:

The embryos of monocotyledons (Fig. 2.31 H) have only one cotyledon. In grass family (Gramineae), this cotyledon is called scutellum. It is situated towards lateral side of embryonal axis. This axis at its lower end has radicle and root cap enclosed in a sheath called coleorhiza.

The part of axis above the level of attachment of scutellum is called epicotyl. It has as shoot apex and few leaf primordia enclosed in a hollow foliar structure called coleoptile. Epiblast represents rudiments of second cotyledon.

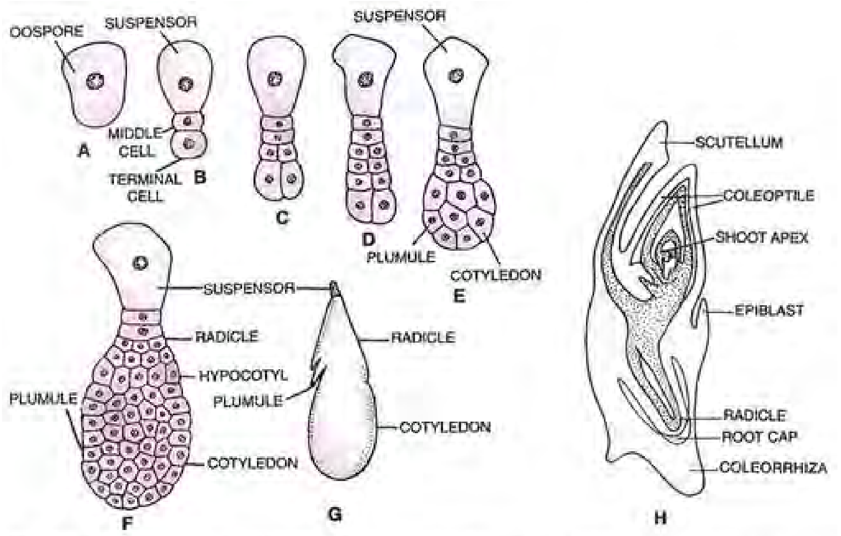


Fig. 2.31. A–G; Stages in development of a monocot embryo. H, a monocot embryo of a grass.

Ovule- types, development of female gametophyte and fertilization

Ovule Definition

The ovule is part of the makeup of the female reproductive organ in seed plants. It’s the place where female reproductive cells are made and contained, and it is what eventually develops into a seed after *fertilization*, only for the seed to then ripen and produce a complete adult plant. Ovules are contained in ovaries at the bottom of a vase-like structure, the carpel, which has a neck called a style and an opening at the top, called a stigma.

After fertilization the ovule starts to swell and its wall starts to toughen up in preparation to become a seed, while the ovary starts to grow around it and becomes the fruit. Keep in mind that some plants, like the avocado, have a single ovule in their ovary, while others, like the kiwifruit, have many, which develop into many seeds in the fruit. Another way that plants differ with regards to their ovules is the place where the ovules are found. Specifically, in *gymnosperms*, such as conifers, the ovules are found on the scales of female cones, while in *angiosperms*, which are flowering plants, the ovules are found inside of the ovary within the carpel.

Components of Ovules

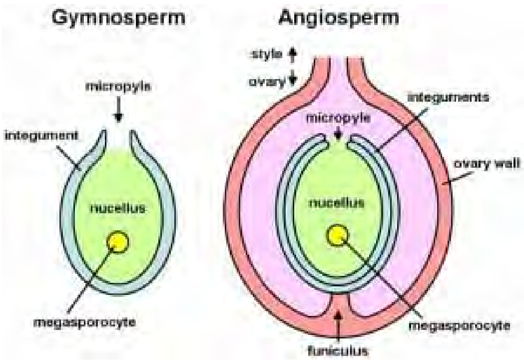
The ovule is made up of the nucellus, the integuments that form the outermost layer, and the female gametophyte (called an embryo sac in flowering plants), which are found at the very center.

The Nucellus

The nucellus is the largest part of the ovule. It houses the embryo sac as well as nutritive tissue and actually remains present in some flowering plants after fertilization as a source of nutrients for the embyo.

The Integuments

The integument is the tough outer protective layer of the ovule. In the diagrams below we can see that gymnosperms, such as pine trees and spruce trees, usually have one integument in an ovule, so we call them unitegmic. On the other hand, angiosperms, like maples and daisies, typically have two integuments, and we call them bitegmic. The integument encloses the nucellus except for a small gap, which is called the *micropyle*.



Plant ovules

The Female Gametophyte

This is the part of the ovules that contains the gamete-producing sex organs, which are critical for sexual reproduction. The female gametophyte contains a single set of unpaired chromosomes, meaning that it's haploid. Note that it is commonly called the embryo sac or *megagametophyte*.

Types of Ovules

Ovules have been separated into six categories based on their shapes:

Orthotropous (Atropous)

This is where the body of these ovules is straight so that the chalaza, where the nucellus and integuments merge, the *funicle*, which attaches the ovule to the placenta, and the *micropyle* are all aligned.

Anatropous

In this case, the ovules become completely inverted during development so that the micropyle lies close to the hilum. The hilum is a scar that marks the point where the seed was attached to the fruit wall by the funicle.

Hemi-anatropous

The body of these ovules becomes at a right angle in relation to the funicle, so it looks like the ovule is lying on its side.

Campylotropous

The body of this type is bent and the alignment between the chalaza and micropyle is lost. The embryo sac is only slightly curved.

Amphitropous

The body of the ovule is very much curved that the embryo sac and the ovule itself take the shape of a horseshoe.

Circinotropous

The funicle in this case is especially long that it creates a nearly full circle around the ovule whose micropyle is ultimately pointing upwards.

Functions of Ovules

The ovule plays a vital role in sexual reproduction. Once a pollen grain lands on the stigma of a flower of its same species, it sends out a pollen tube down through the style. This tube then enters the ovary and reaches the ovule of the plant. Once that occurs, fertilization can arise as the nucleus of the pollen grain is sent down the tube to merge with the nucleus in the embryo sac. Note that the male alternative to the ovule is pollen, which contains the male gametophytes.