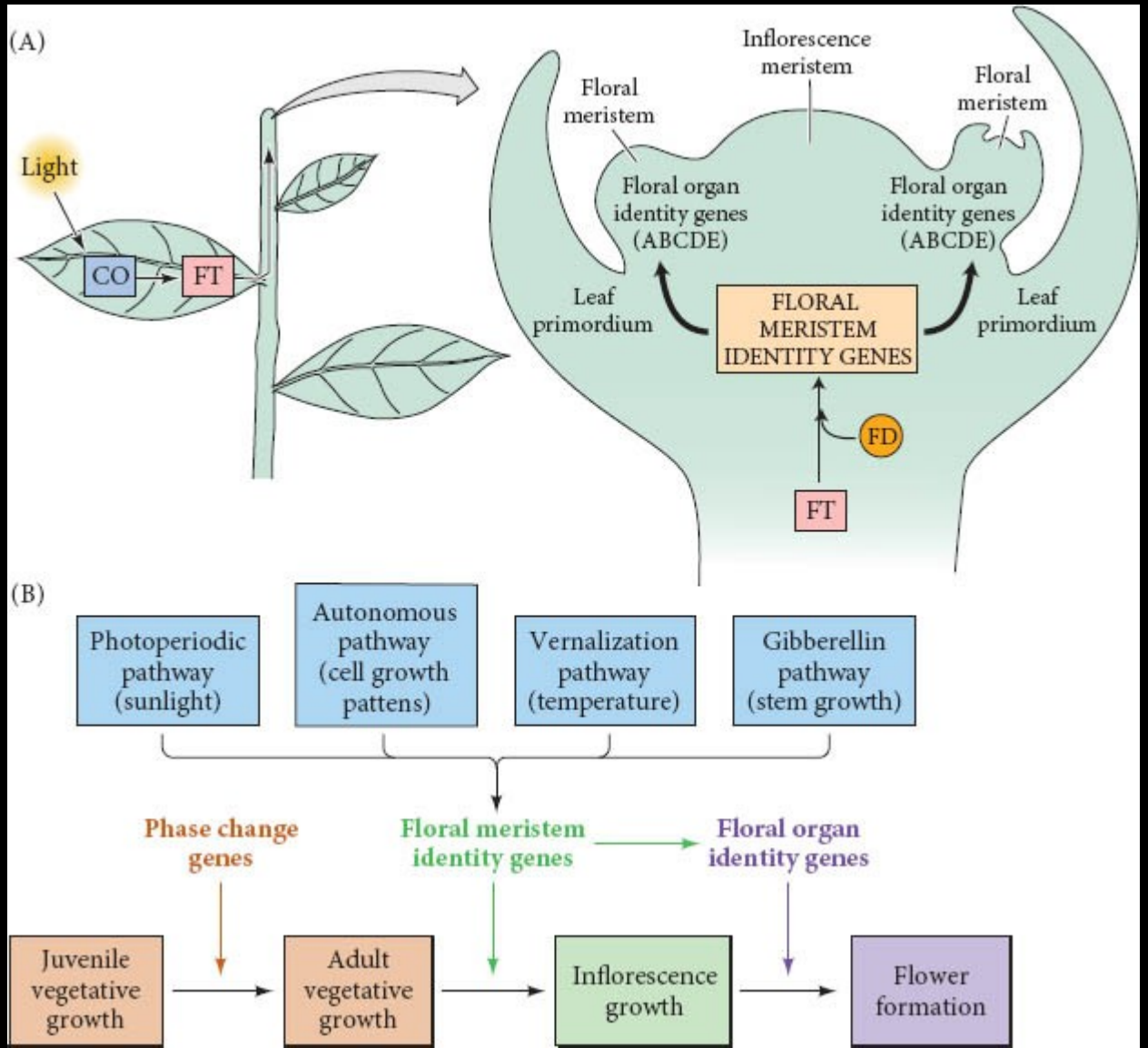
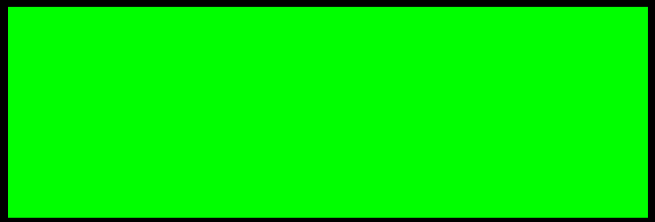
MORPHOGENESIS & ORGANOGENESIS IN PLANTS

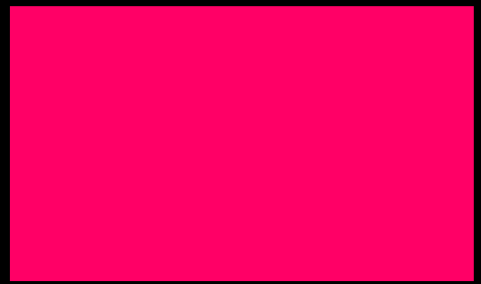
What are MADS box genes?

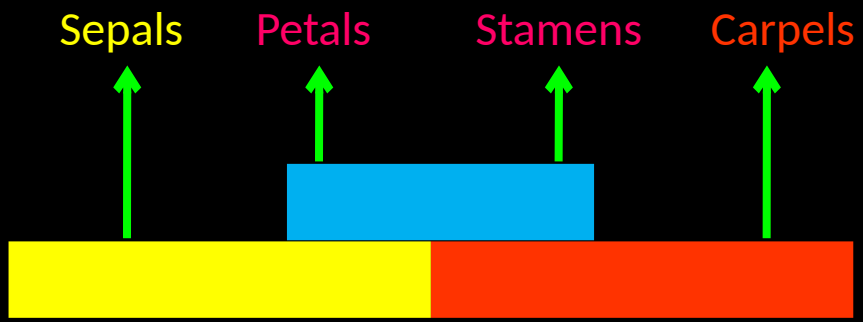
- The MADS box is a **highly conserved sequence motif** found in a family of transcription factors.
- The conserved domain was recognized after the first four members of the family, which were MCM1, AGAMOUS, DEFICIENS and SRF (serum response factor). The name MADS was constructed form the "initials" of these four "founders".
- Length of the MADS-box reported by various researchers varies somewhat, ***but typical lengths are in the range of 168 to 180 base pairs.***

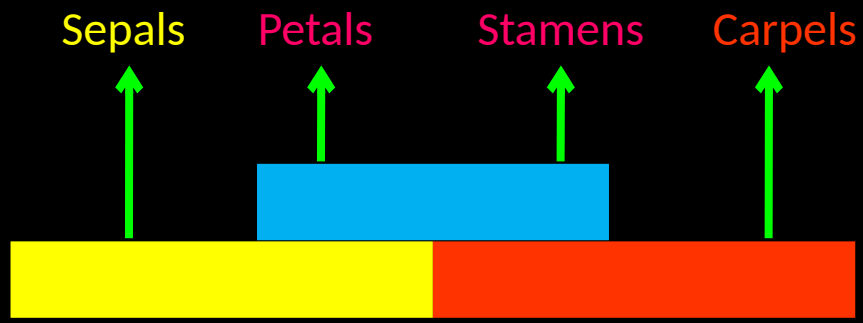

(A)
Light
CO
FT
Inflorescence meristem
Floral meristem
Floral meristem
Floral organ identity genes (ABCDE)
Floral organ identity genes (ABCDE)
Leaf primordium
FLORAL MERISTEM IDENTITY GENES
Leaf primordium
FD
FT
(B)
Photoperiodic pathway (sunlight)
Autonomous pathway (cell growth pattens)
Vernalization pathway (temperature)
Gibberellin pathway (stem growth)
Phase change genes
Floral meristem identity genes
Floral organ identity genes
Juvenile vegetative growth
Adult vegetative growth
Inflorescence growth
Flower formation





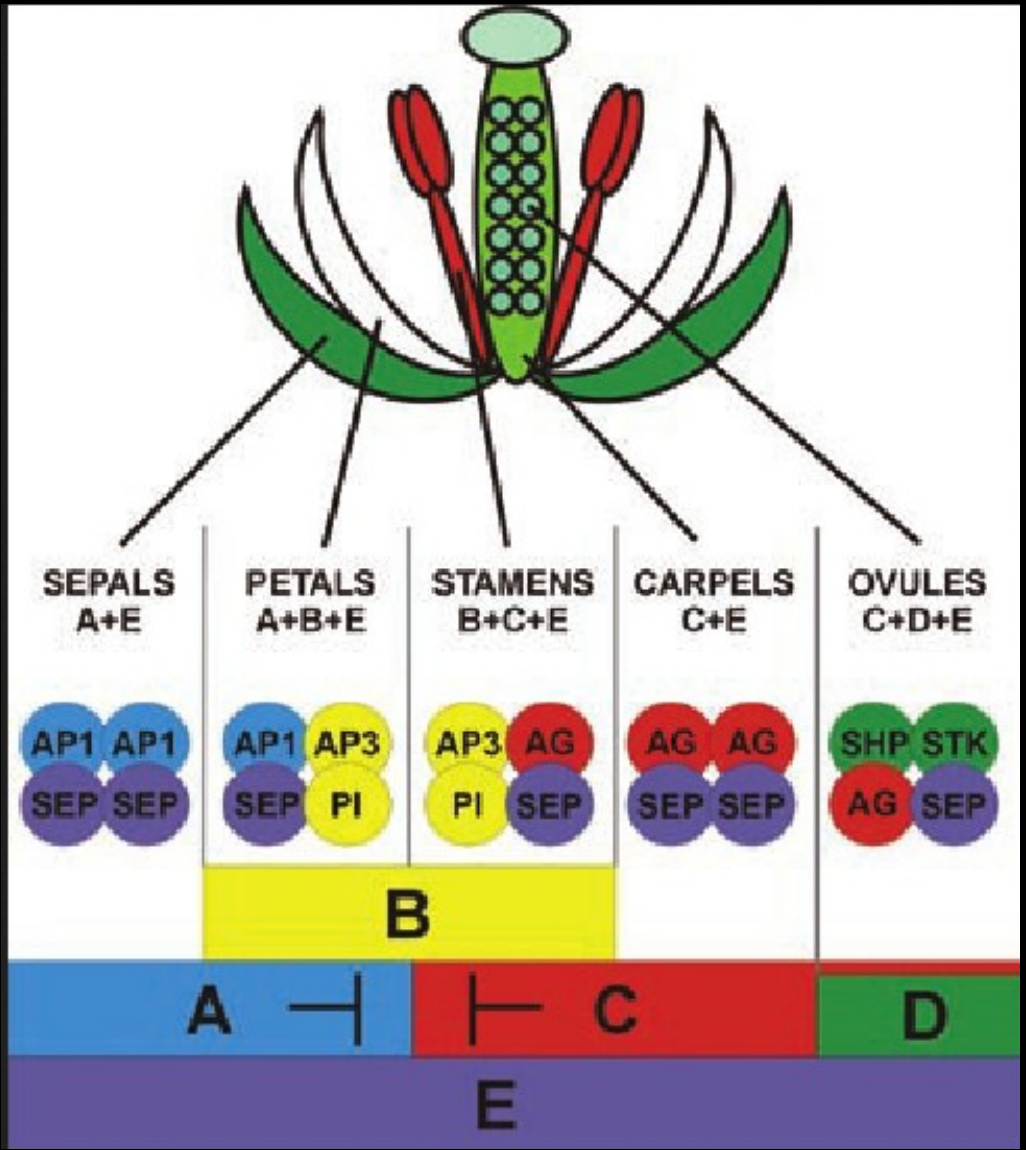




Sepals
Petals
Stamens
Carpels


Sepals
Petals
Stamens
Carpels

Phenotypic Effects of Mutations in A, B or C Function Floral Identity Genes

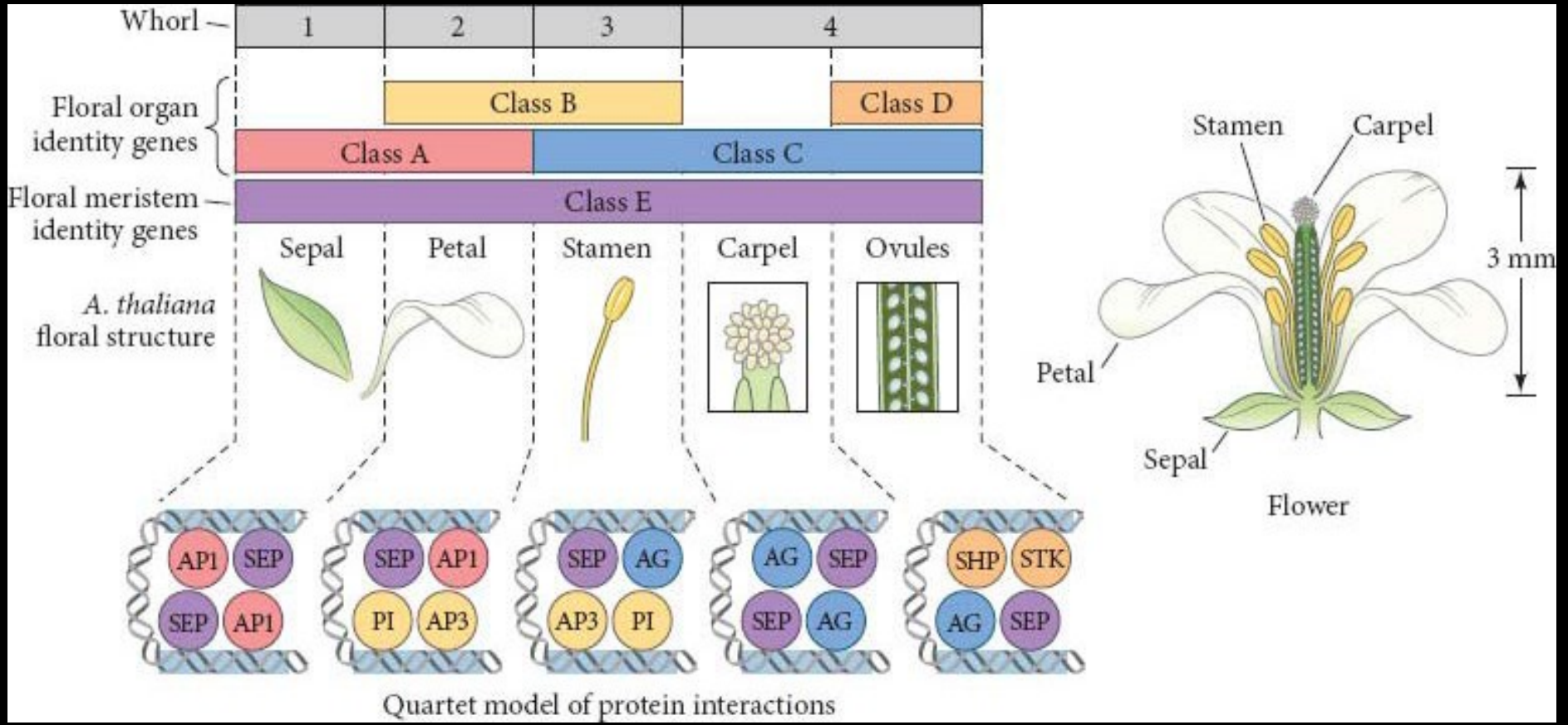
	Phenotype			
Mutation	**Whorl 1**	**Whorl 2**	**Whorl 3**	**Whorl 4**
Wild Type	Sepal	Petal	Stamen	Carpel
A Function	Carpel	Stamen	Stamen	Carpel
B Function	Sepal	Sepal	Carpel	Carpel
C Function	Sepal	Petal	Petal	New Flower



The ABC model has been gradually expanded to include class D- & E-function genes necessary for ovules & floral whorls.

D-function genes: SEEDSTICK (STK) + SHATTERPROOF1 & 2 (SHP1 & SHP2)

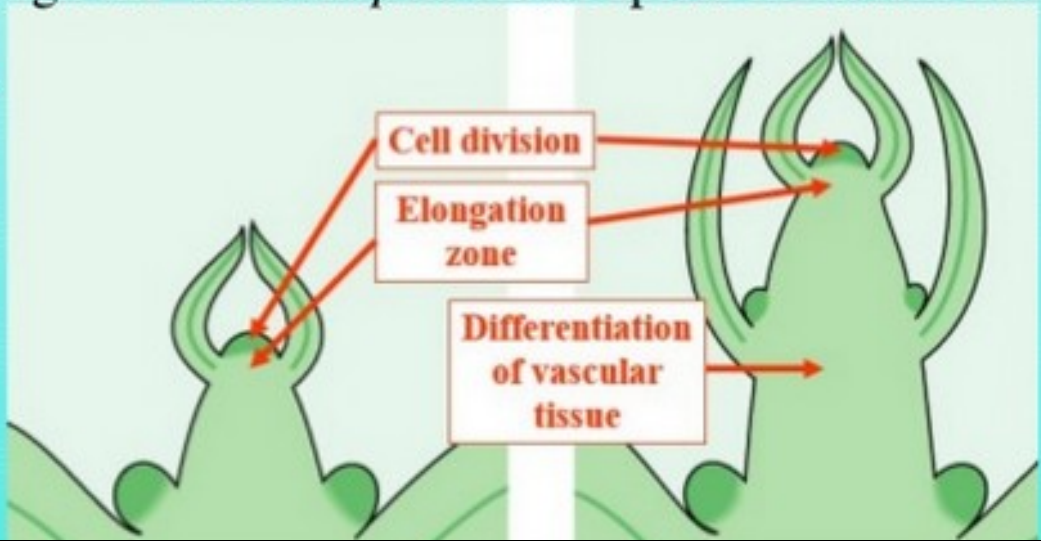
E-function genes requires at least one of the four SEPALLATA (SEP1, SEP2, SEP3 and SEP4)



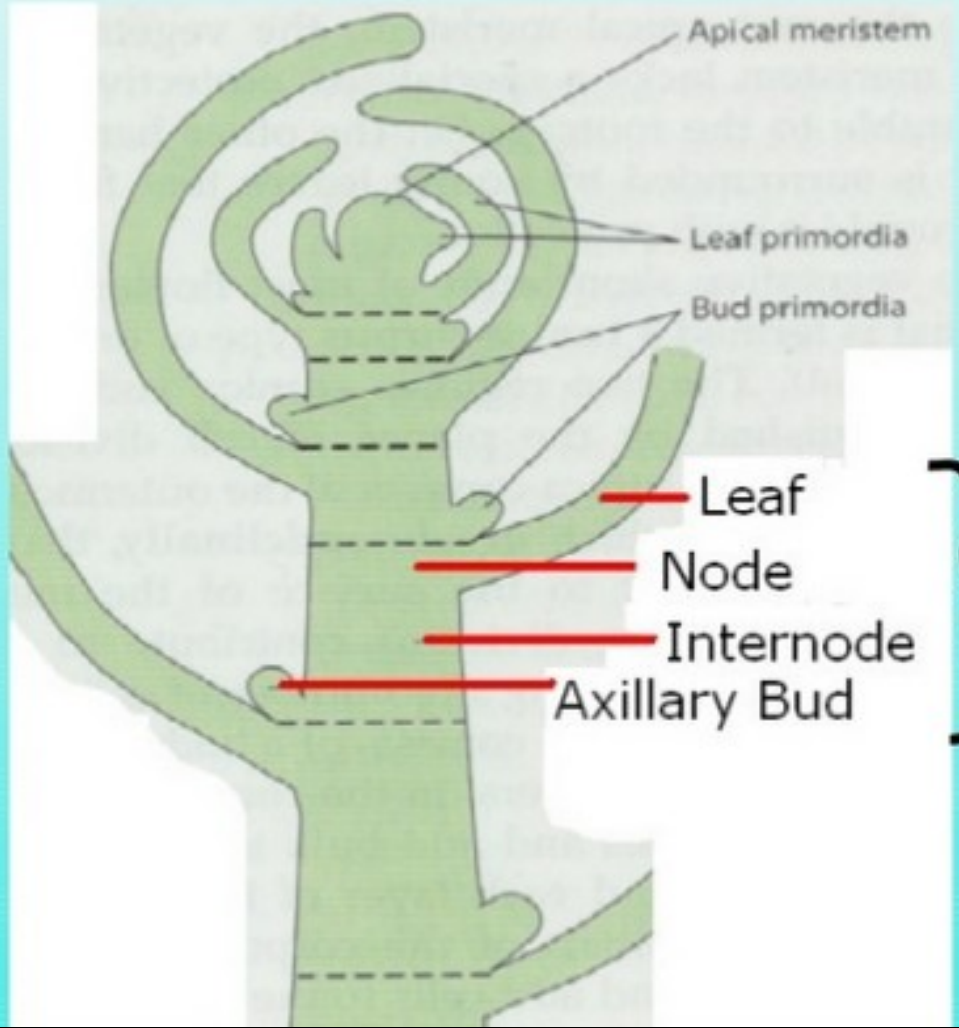
Quartet model of protein interactions

Shoot Apical Meristem (SAM)

- The vegetative shoot apical meristem generates the stem, as well as the lateral organs attached to the stem (leaves and lateral buds).
- The shoot apical meristem typically contains a few hundred to a thousand cells, although the *Arabidopsis* shoot apical meristem has only about 60 cells.



Shoot organization - Phytomeres



Phytomer = modular unit of the Shoot

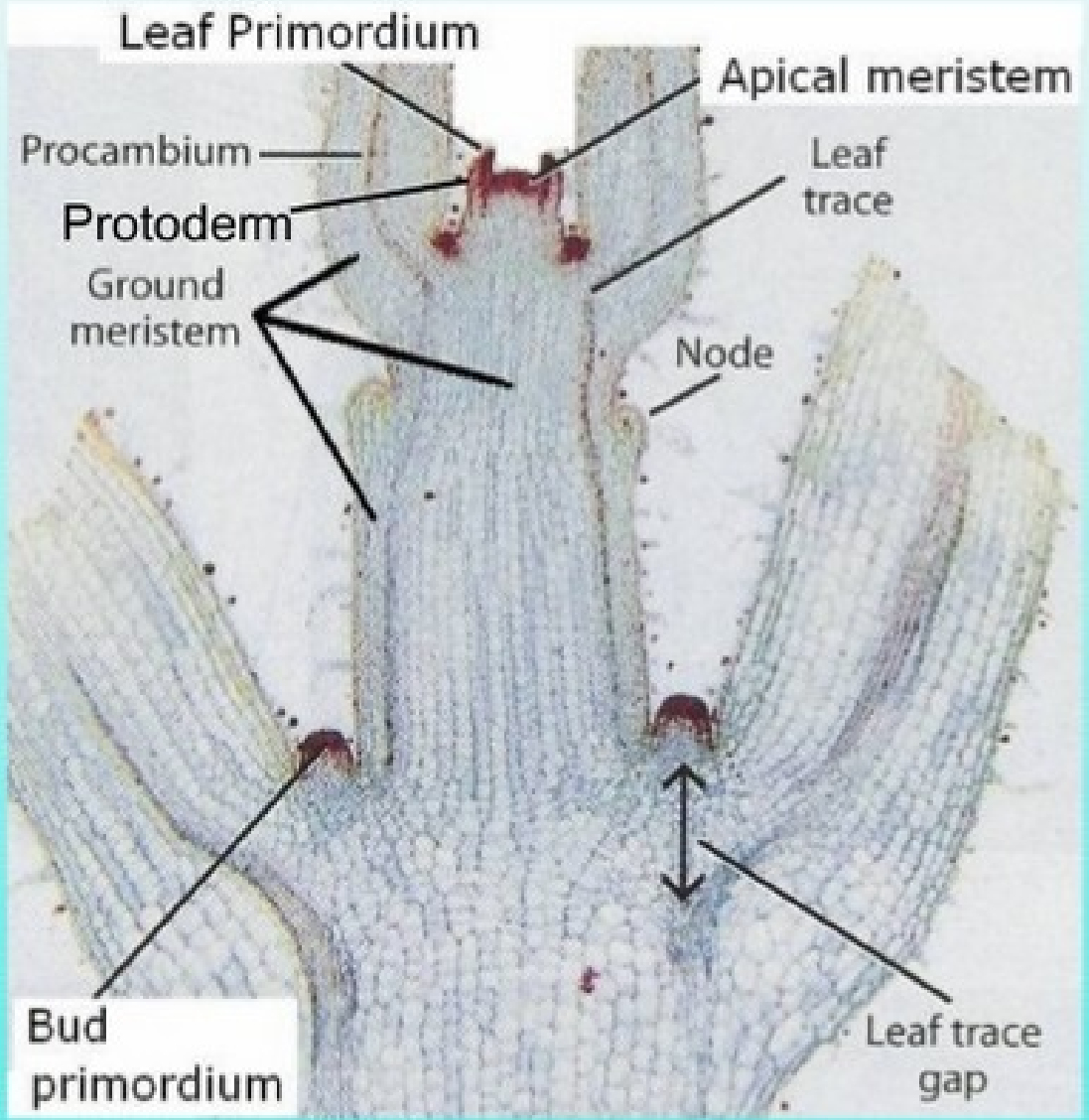
Shoot organization

Apical Meristem

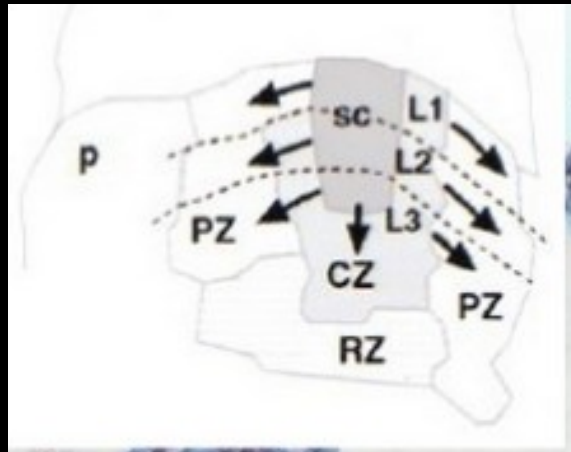
↓

Primary Meristems

- Protoderm
- Procambium
- Ground Meristem



Shoot apical meristem organization



Stem Cells

Central Zone

L1 = tunica

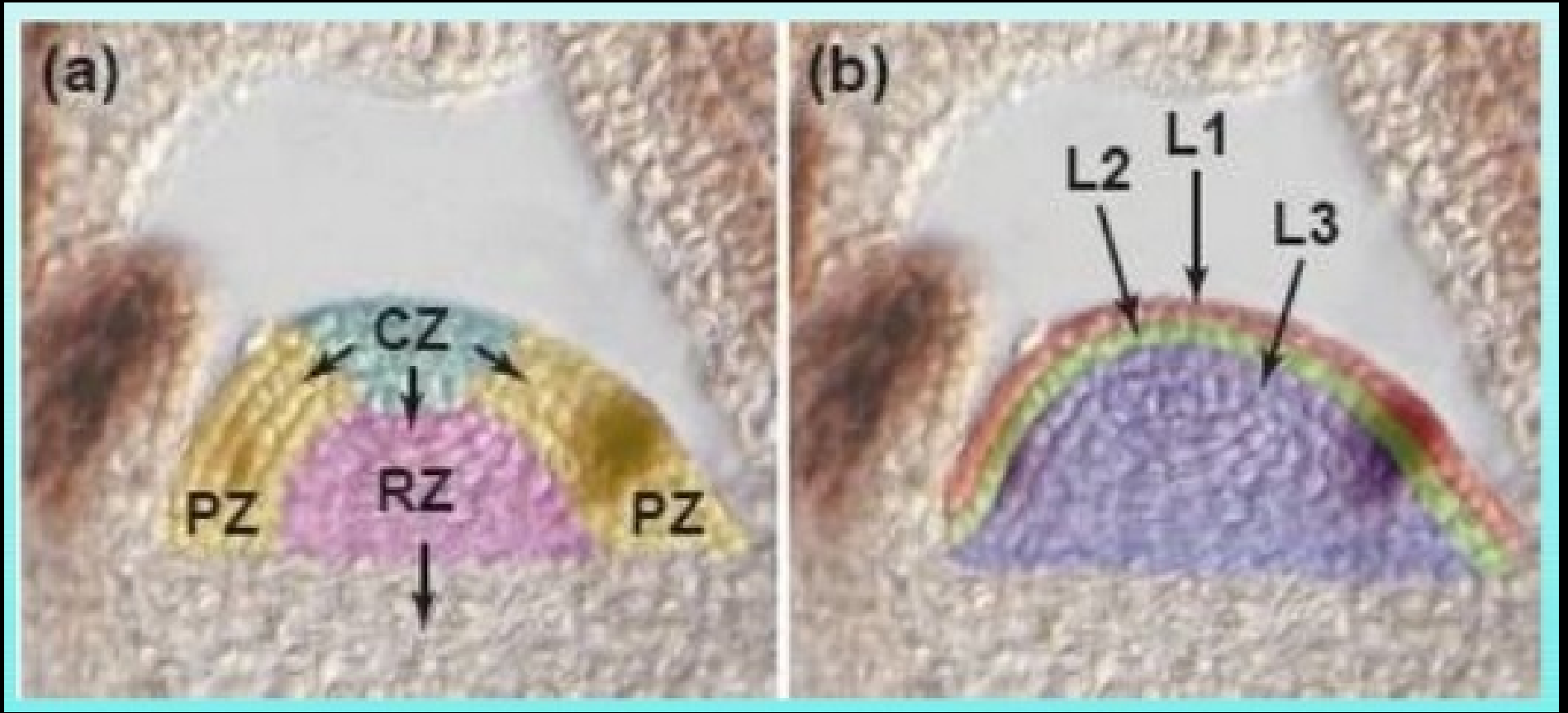
L2 = tunica

L3 = corpus

Peripheral Zone

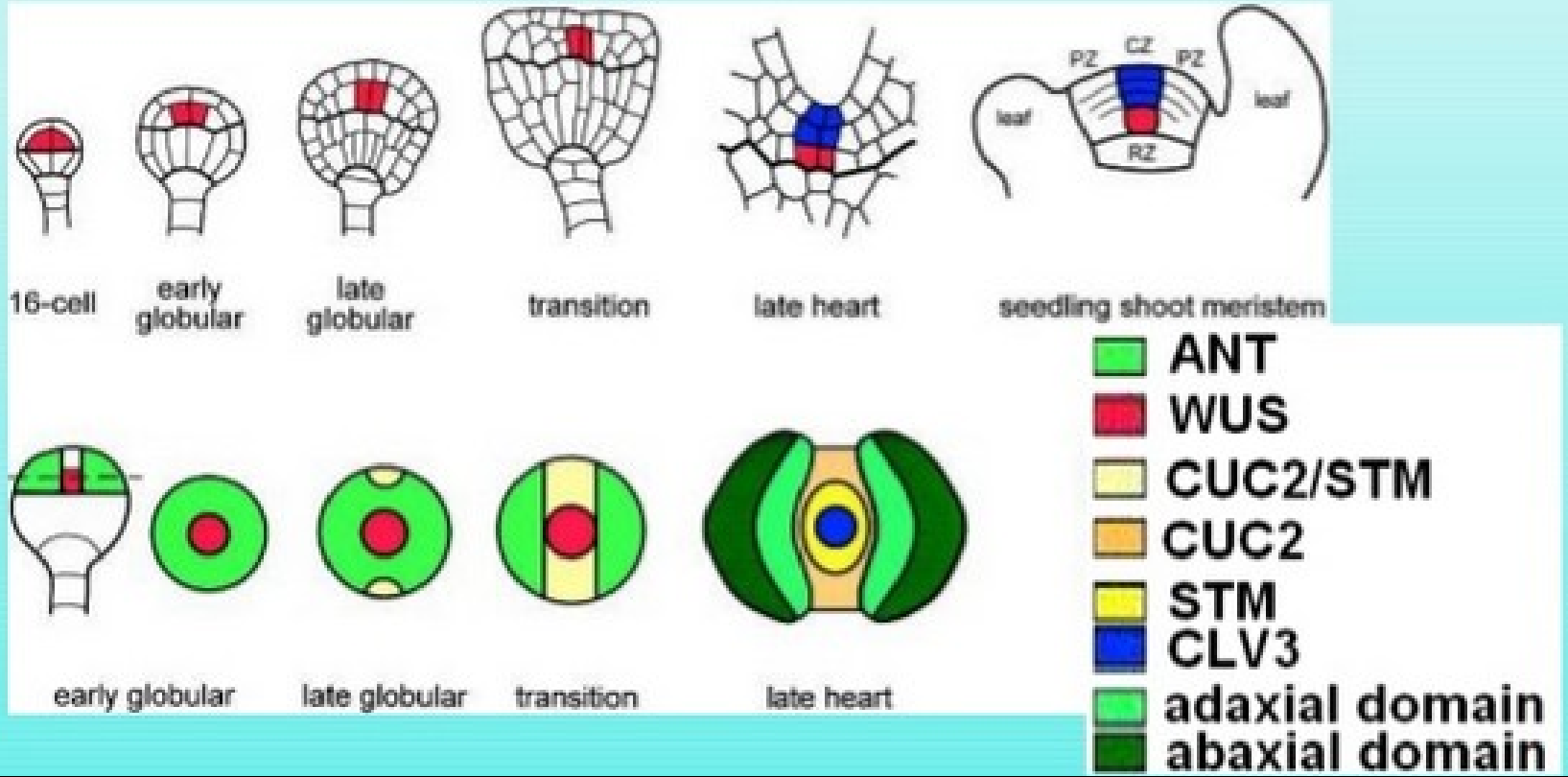
Pith or Rib Meristem

Organizing Center

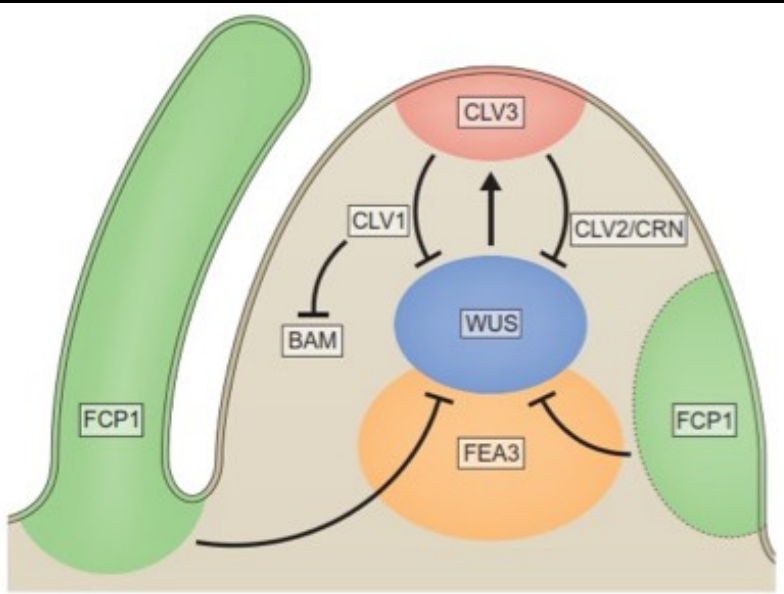

(a)
CZ
PZ
RZ
PZ
(b)
L2
L1
L3

Gene Expression in the Apical Embryo Domain

WUSCHEL (WUS), CLAVATA (CLV) AND SHOOT MERISTEMLESS (STM)



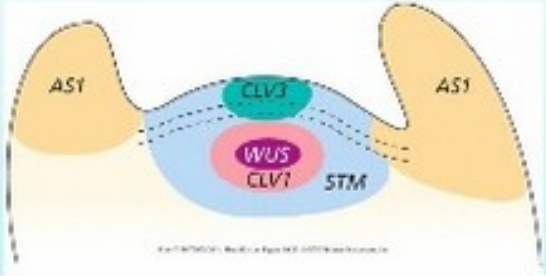
Shoot Development Genes



WUSCHEL (WUS) → Stem cell promoting transcription factor

CLAVATA3 (CLV3) → Differentiation promoting peptide

Somssich et al., Development (2016) 143, 3238-3248



WUS, CLV and STM expression in the shoot apex

WUS gene

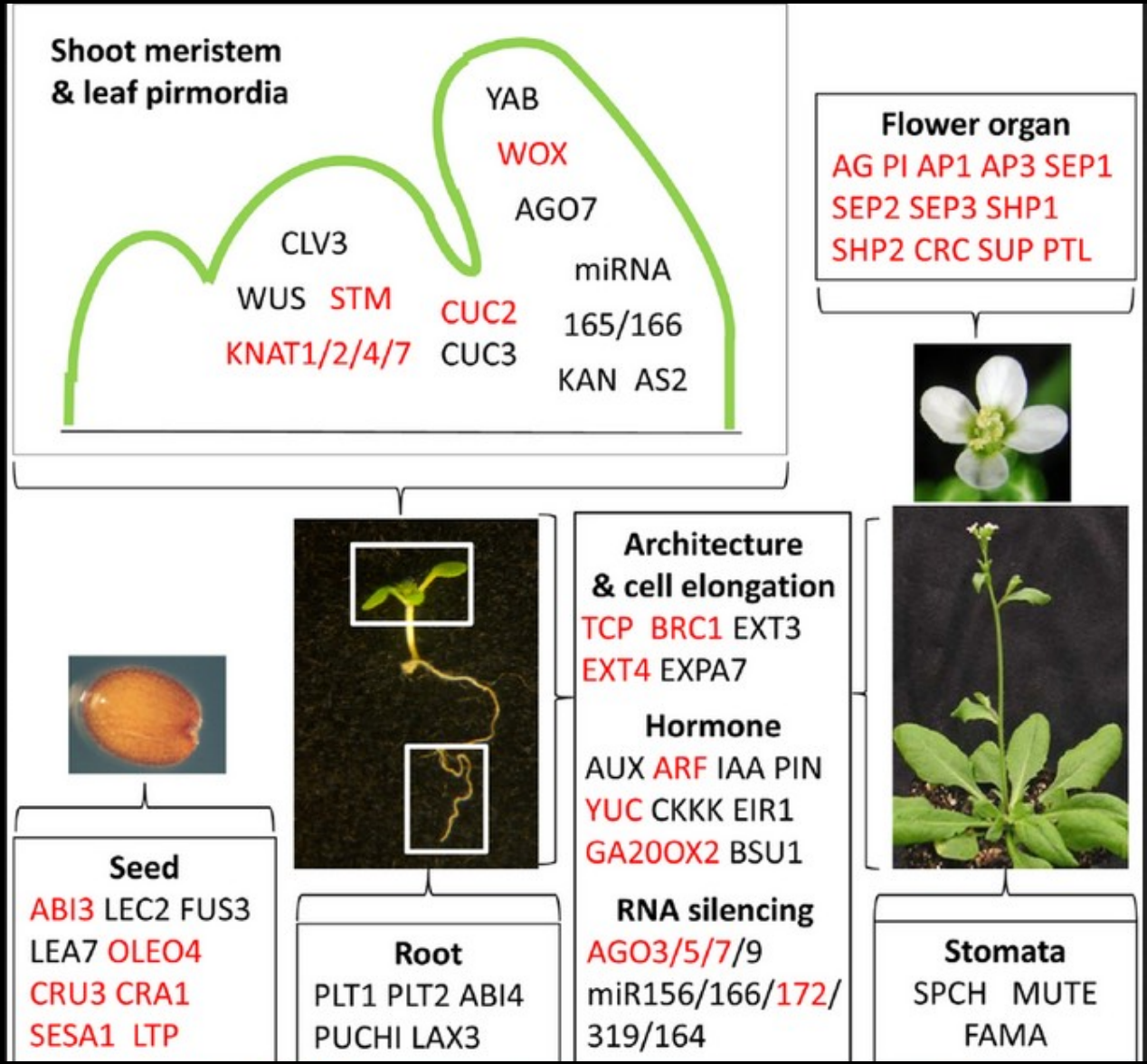
1. Organizing Center of Central Cells (just a few cells)
2. Molecular: Encodes homeodomain protein
3. Molecular Genetic: Induces Expression of CLV3
4. Developmental: WUS specifies stem cells of the SAM, i.e. maintains stem cells and maintains their identity.

CLV3 gene

1. Stem cells of Central Zone
2. Molecular: Encodes peptide secreted in extracellular space
3. Molecular Genetic: Inhibits WUS expression.
4. Developmental: CLV3 restricts size of Central Cells, i.e. CLV3 restricts size of the stem cell population.

STM gene

1. Through SAM apical "dome" of cells: central zone and peripheral zone.
2. Molecular: Encodes homeodomain protein
3. Molecular Genetic: Blocks organ formation genes (AS1, AS2)
4. Developmental: Prevents premature differentiation of cells from Peripheral Zone… thus prevents premature organ initiation.


Shoot meristem
& leaf pirmordia
YAB
WOX
AGO7
CLV3
WUS STM
KNAT1/2/4/7
CUC2
CUC3
miRNA
165/166
KAN AS2
Flower organ
AG PI AP1 AP3 SEP1
SEP2 SEP3 SHP1
SHP2 CRC SUP PTL
Architecture
& cell elongation
TCP BRC1 EXT3
EXT4 EXPA7
Hormone
AUX ARF IAA PIN
YUC CKKK EIR1
GA20OX2 BSU1
RNA silencing
AGO3/5/7/9
miR156/166/172/
319/164
Seed
ABI3 LEC2 FUS3
LEA7 OLEO4
CRU3 CRA1
SESA1 LTP
Root
PLT1 PLT2 ABI4
PUCHI LAX3
Stomata
SPCH MUTE
FAMA

CLV3 Peptide

- The CLV3 gene encodes a small 96-amino-acid polypeptide
- 18-amino-acid secretion signal at the amino terminus
- Mature peptide is post transcriptionally modified 12-amino acid peptide

- Helps in the maintenance of stem cell reservoirs in shoot apical meristems (SAMs)
- A key factor in controlling stem cell identity is the *WUSCHEL* (*WUS*) gene, which encodes a WOX homeodomain transcription factor essential for stem cell maintenance
- *WUS* is expressed in the meristem organizing center (OC) and promotes CK responses by repressing A-type *ARR* gene expression

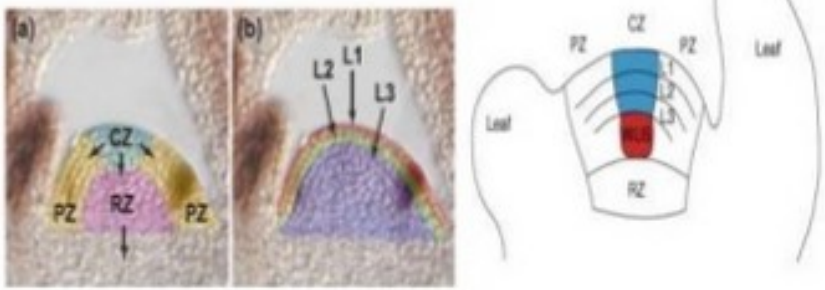
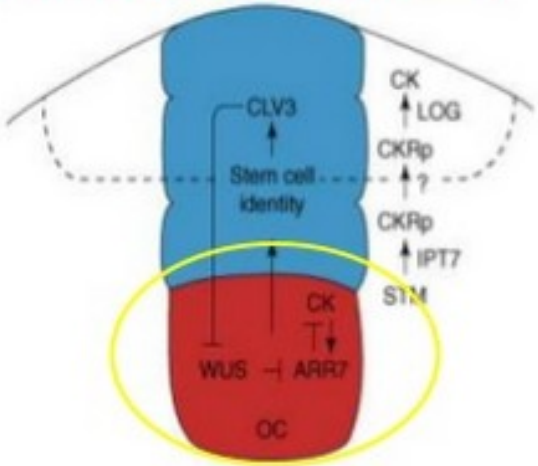


Fig: SAM and WUS location

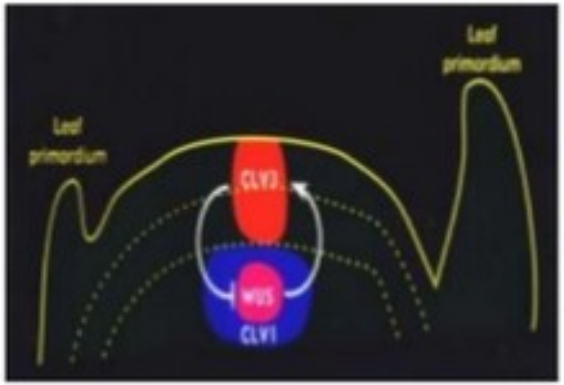


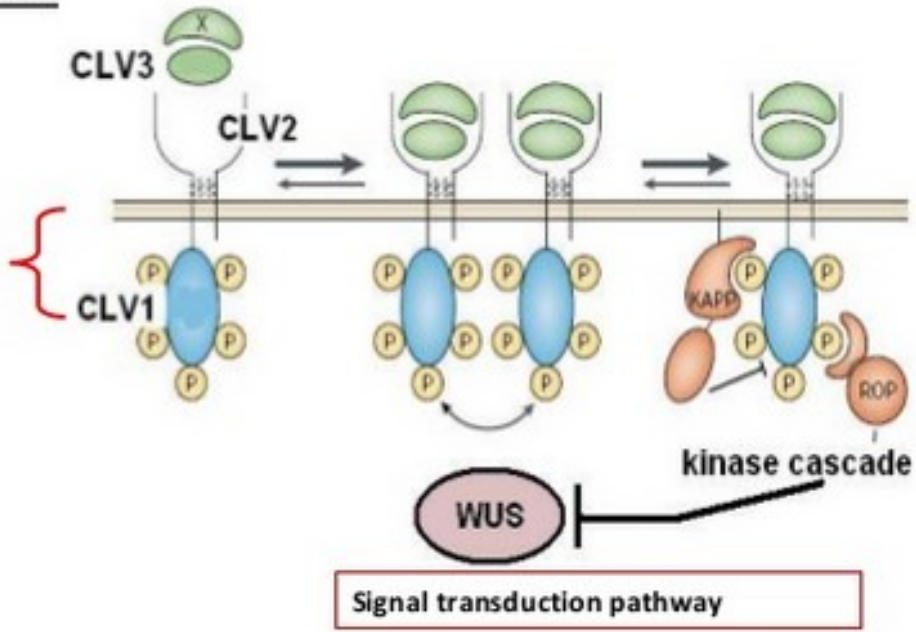
WUS Pathway

Tucker et al.2014

Shoot Development : Genetics

CLAVATA gene mechanism





CLAVATA GENE Characteristics

CLV1 – Extracellular polypeptide: 96 amino acids.*(Ser/Thr) kinase*. Extracellular domain is leucine-rich repeats (LRRs)

CLV2 – Membrane-bound protein receptor with a protein-binding motif

CLV3 – Membrane-bound protein receptor with a protein-binding motif and Restricted to L1, L2 of SAM Central Zone

KAPP- The type-2C kinase-associated protein phosphatase

ROP-Ras GTPases are typically associated with cytosolic MAPK cascades

Summary: Shoot Apical Meristem Genetic Influences on Development

1. Organizing Center (OC): Maintains Stem Cells
    a. cells expressing WUS gene confers stem cell fate to overlying stem cells
    b. cells above OC target stem cells by preferred connections through plasmodesmata

2. Stem Cells control boundaries of stem cells
    a. Surgical expts. Demonstrate "release" from inhibition of differentiating "daughter" cells
    b. CLV3 gene inhibits WUS gene expression

3. Daughter cells of stem kept in undifferentiated state
    a. STM gene keeps daughter cells in an undifferentiated state.
    b. Daughter cells increase to sufficient numbers before organ formation

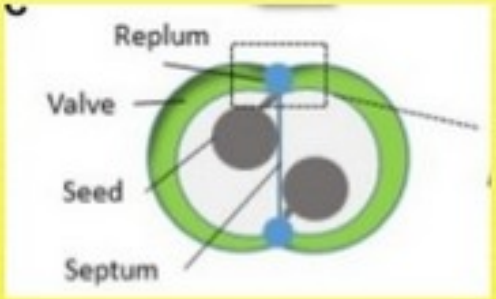
GENES ASSOCIATED WITH RAM

- ✓ *HOBBIT (HBT) genes*
- ✓ *MONOPTEROS (MP) gene is required for formation of the* embryonic primary root as well as vascular development
- ✓ *SHORT ROOT (SHR) genes*
- ✓ *SCARECROW (SCR) genes*

Genes

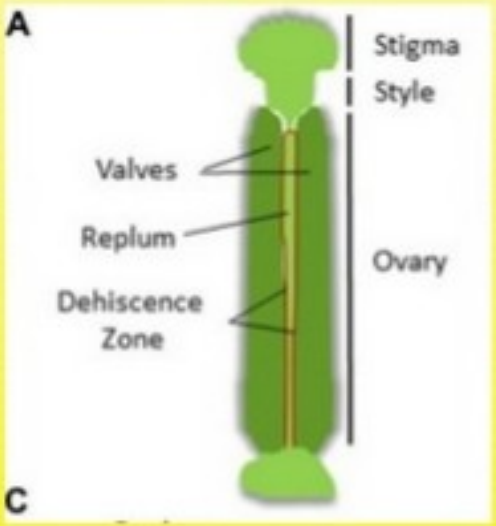
- Arabidopsis fruits develop from two fused carpels and are specialized capsules called siliques
- **FRUITFULL (FUL)** is necessary for proper valve development and represses SHATTERPROOF 1/2 (SHP 1/2)

  (Gu et al., 1998;Ferrándiz et al., 2000a).
- **SHATTERPROOF 1/2 (SHP1/2)** are necessary for valve margin development (Liljegren et al., 2000).
- **REPLUMLESS (RPL)** is necessary for replum development and represses SHP1/2 (Roeder et al., 2003)



- SHP1/2 activate INDEHISCENT (IND) and ALCATRAZ (ALC), which are **both necessary for the differentiation of the dehiscence** zone between the valves and replum (Girin et al., 2011; Groszmann et al., 2011).

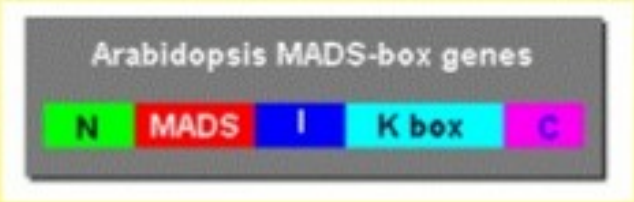
- FUL, SHP1/2, RPL, IND, SPT, and ALC all belong to large **transcription factor families**.
- **FUL and SHP1/2 belong to the MADS-box family** (Gu et al., 1998; Liljegren et al., 2000)



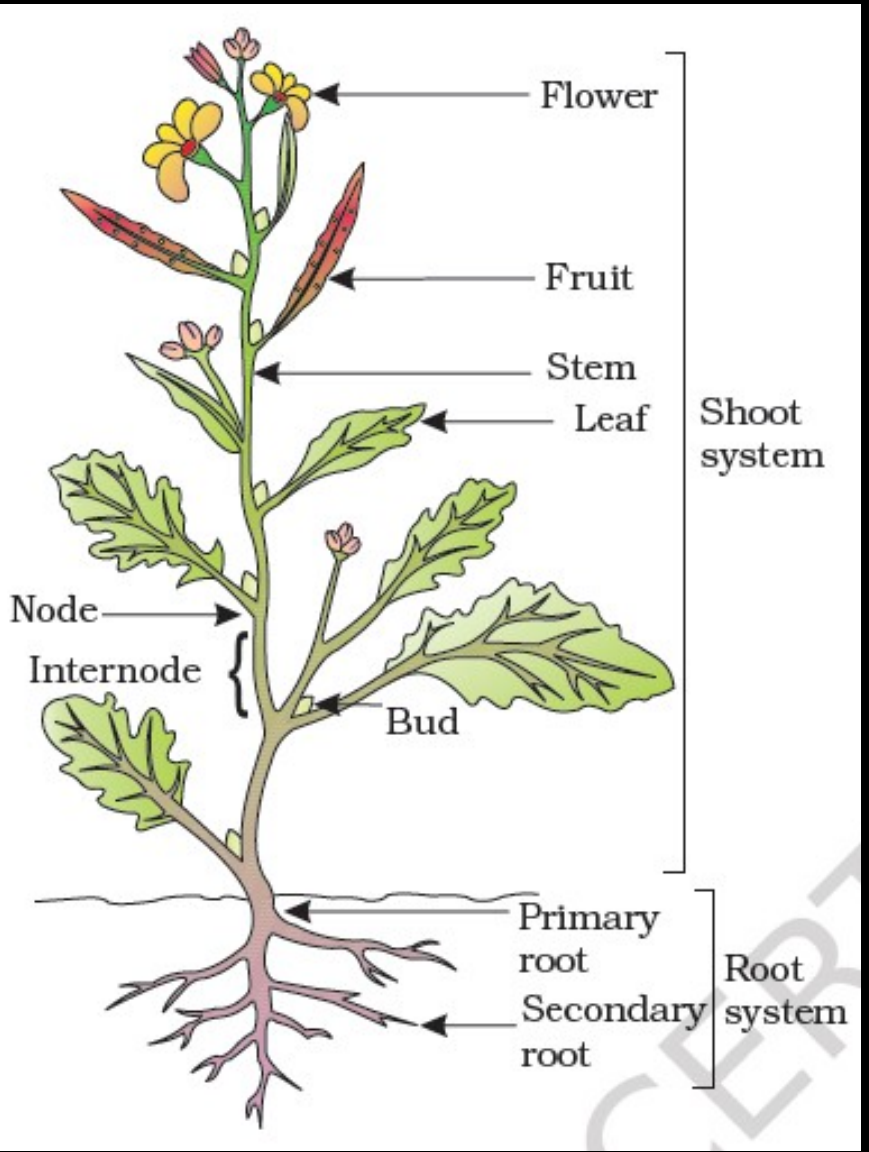
MADS-box family

- MADS-box genes represent a highly conserved gene family of putative transcription factors in plants

- The proteins encoded by these genes are characterized by a highly conserved domain, which consists of 56 amino acids

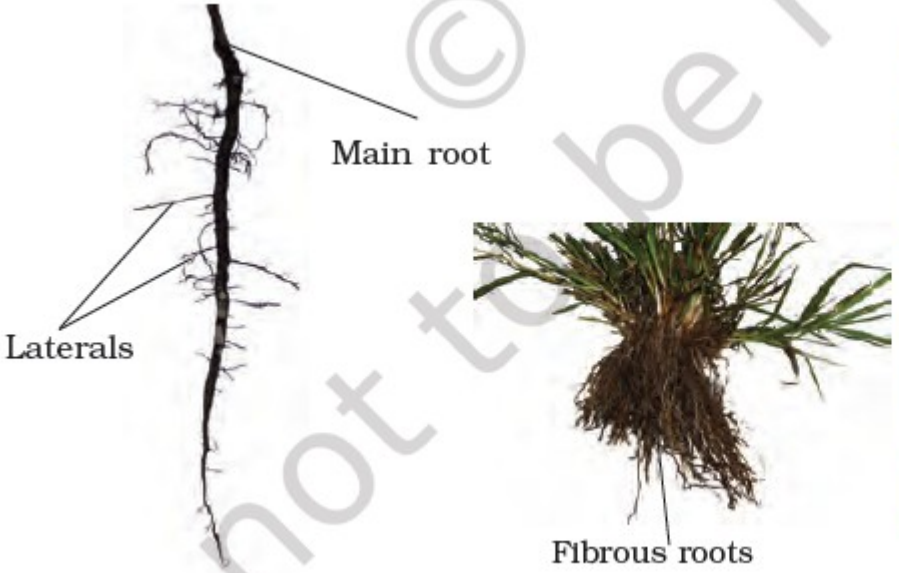


- **K-box** involved in protein-protein interactions.
- The MADS-box and K-box are separated by a weakly conserved **Intervening (I) region**, and a few MADS-box genes have an **amino-terminal** extension (**N**). The **Carboxyl-terminal** (**C**) region may function as a **transcriptional activation domain**.



Dicotyledonous plants: direct elongation of radicle leads to the formation of primary root which grows inside the soil.

It bears lateral roots of several orders that are referred to as secondary, tertiary, etc.



Primary roots and its branches

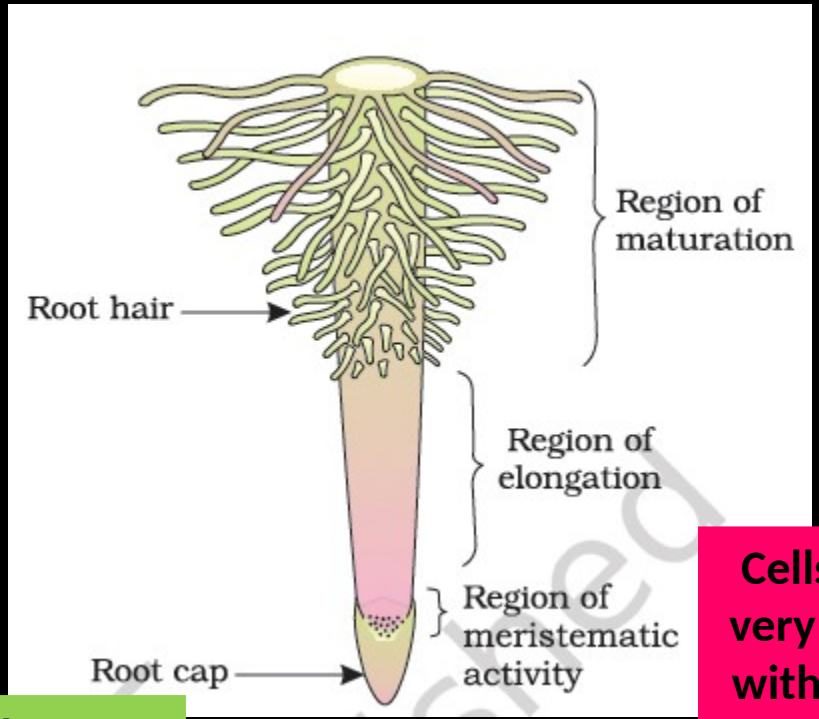
Mustard

In monocots primary root is short lived & replaced by large no. of roots originating from the base of stem (fibrous)

wheat plant

Roots arise from parts of the plant other than the radicle

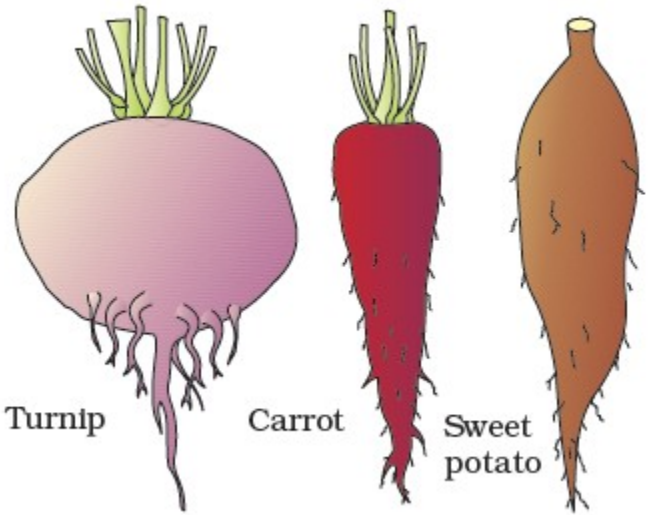
Grass, Monstera, banyan tree

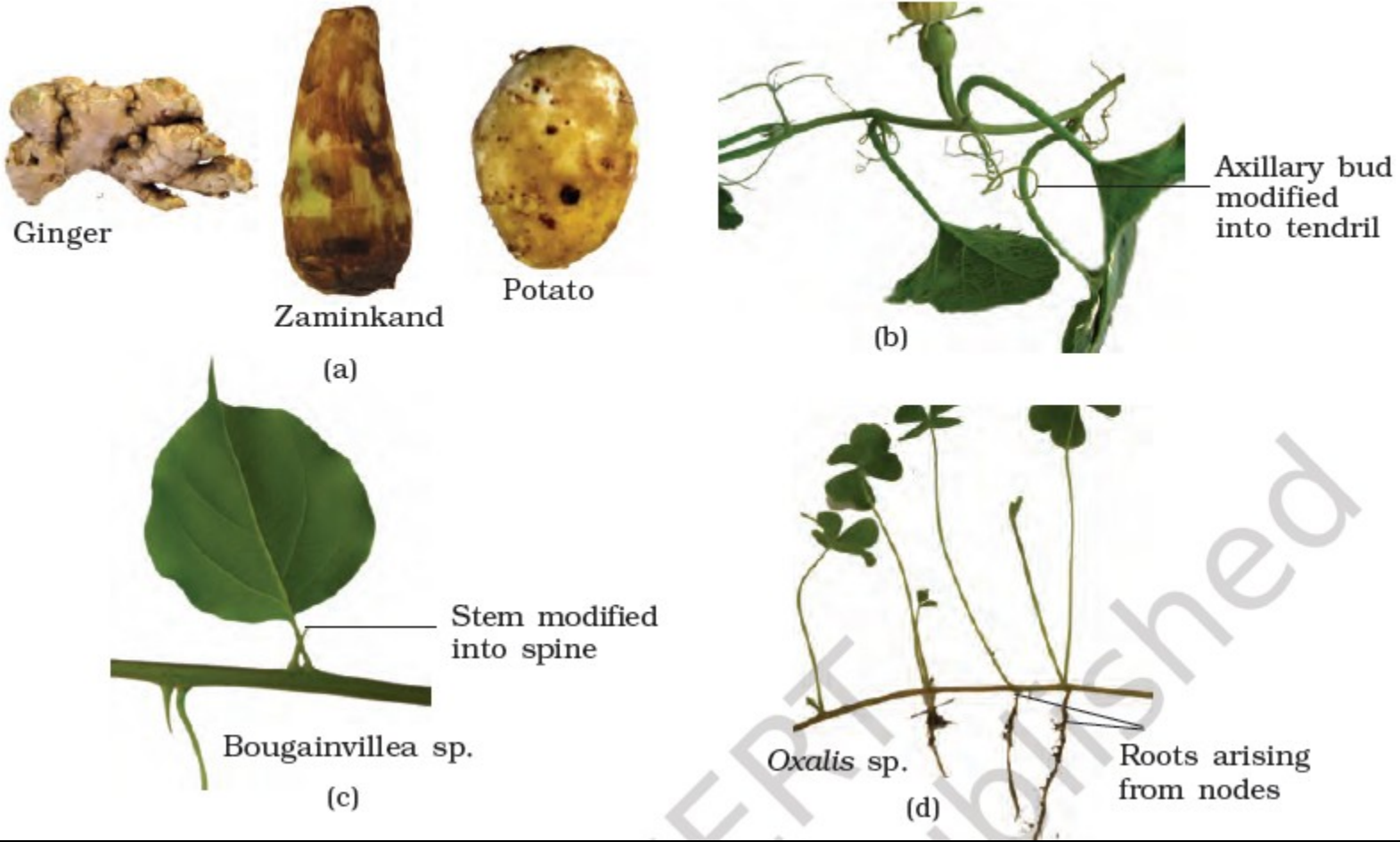


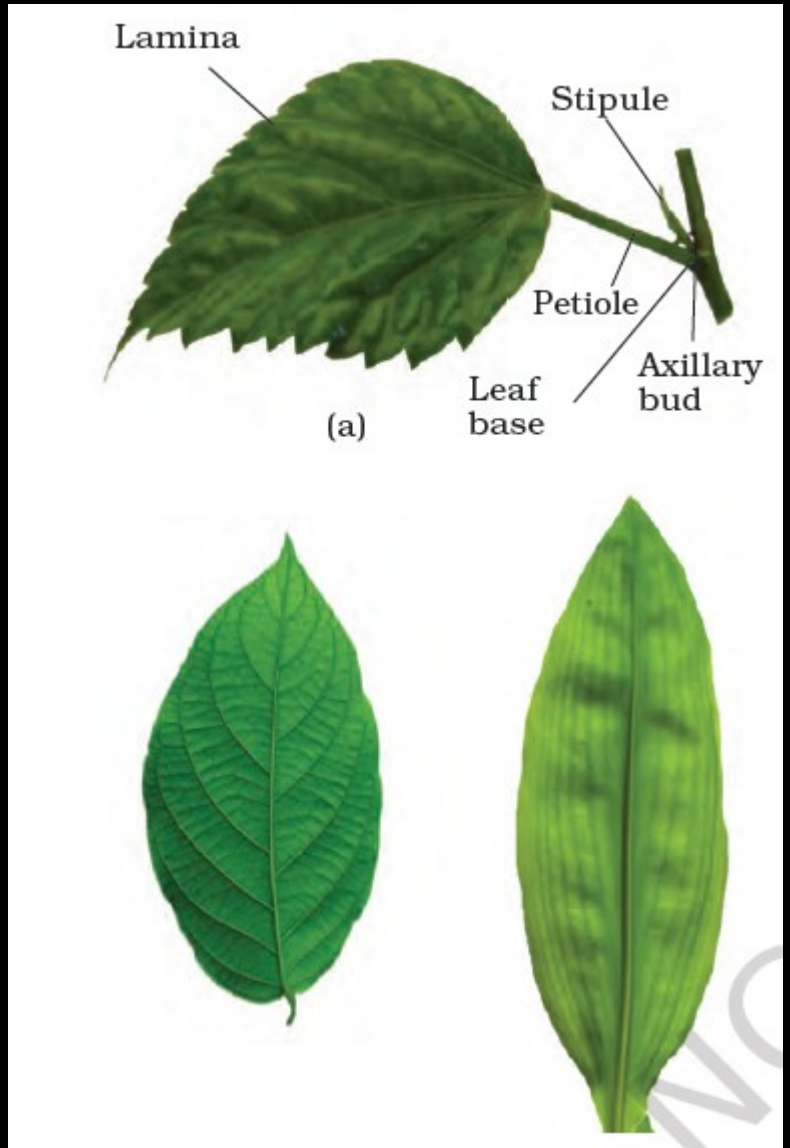
Protects the tender apex of the root as it makes its way through the soil

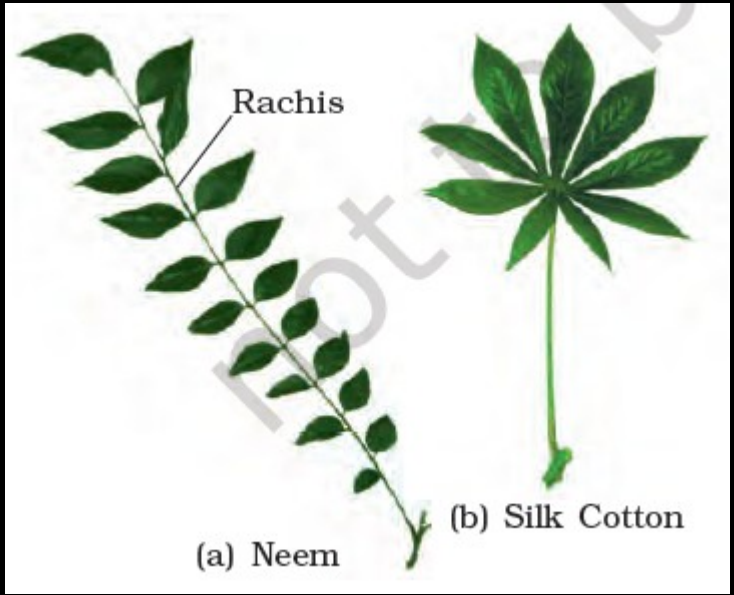
Cells of this region are very small, thin-walled, with dense protoplasm & divide repeatedly

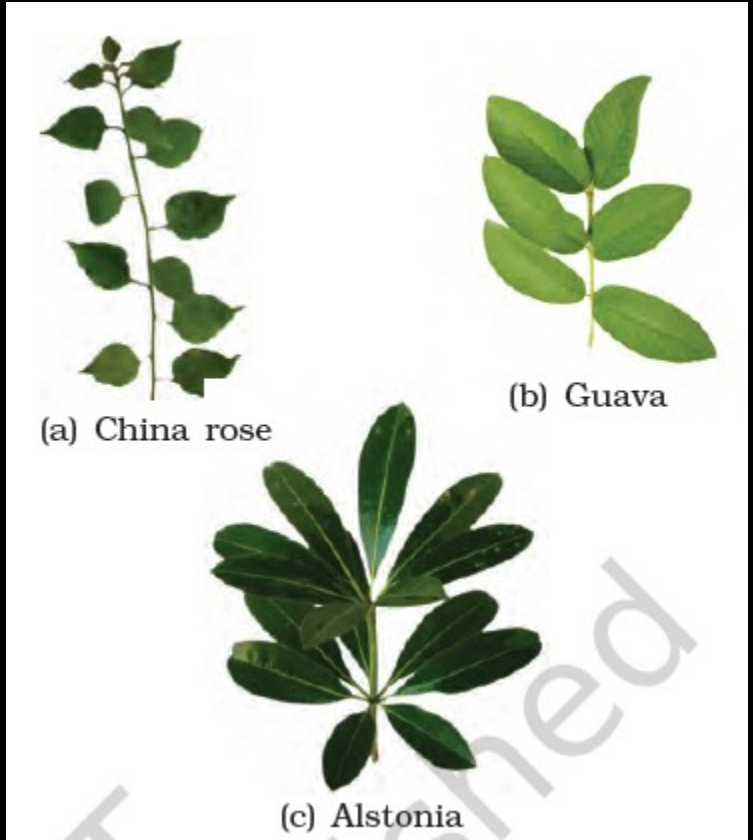
Asparagus

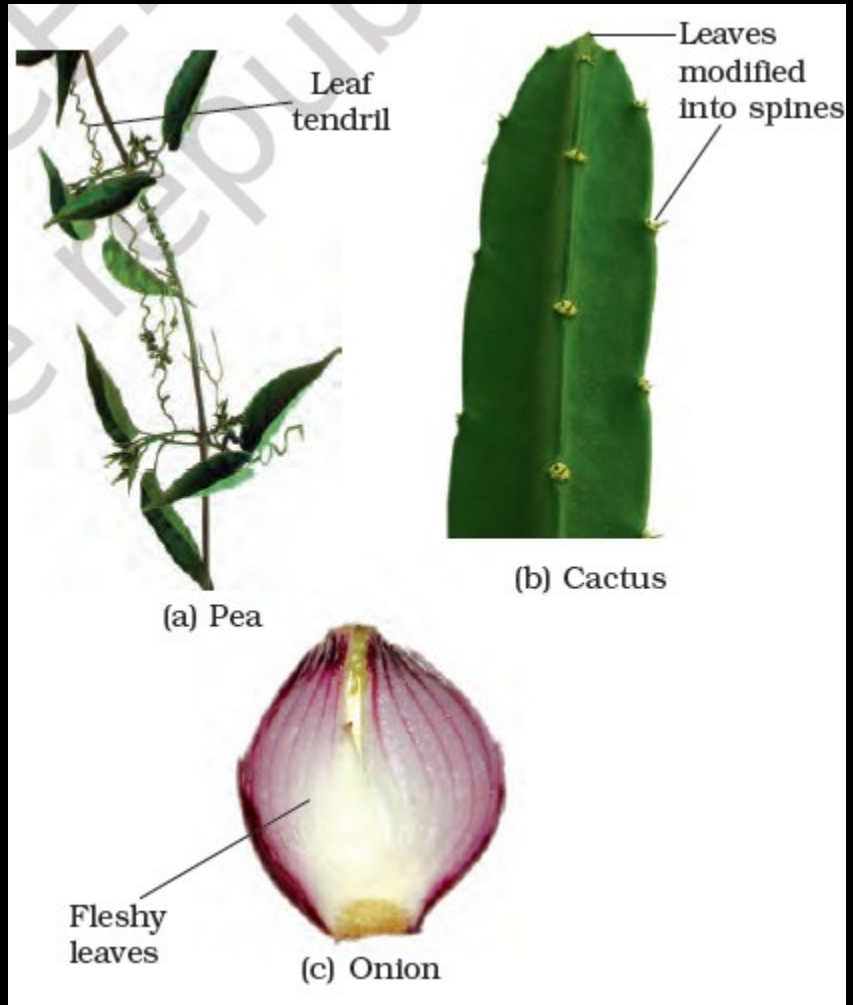


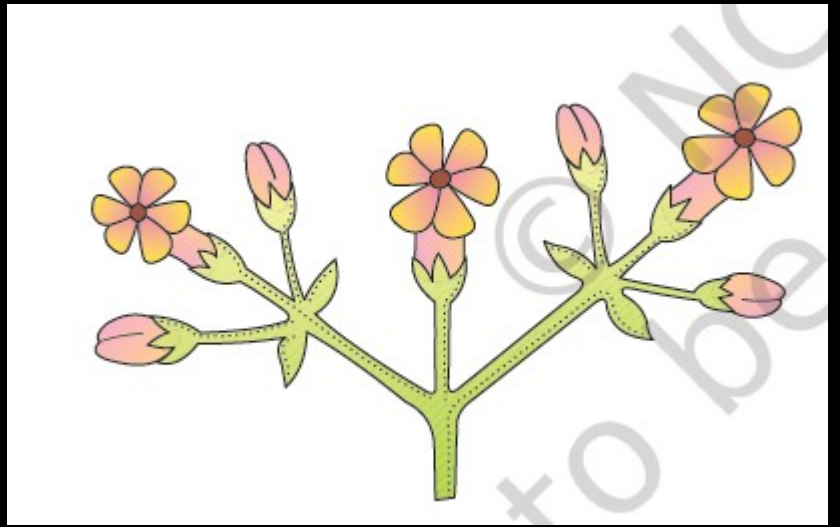

Ginger
Zaminkand
Potato
(a)
Axillary bud modified into tendril
(b)
Stem modified into spine
Bougainvillea sp.
(c)
Oxalis sp.
Roots arising from nodes
(d)

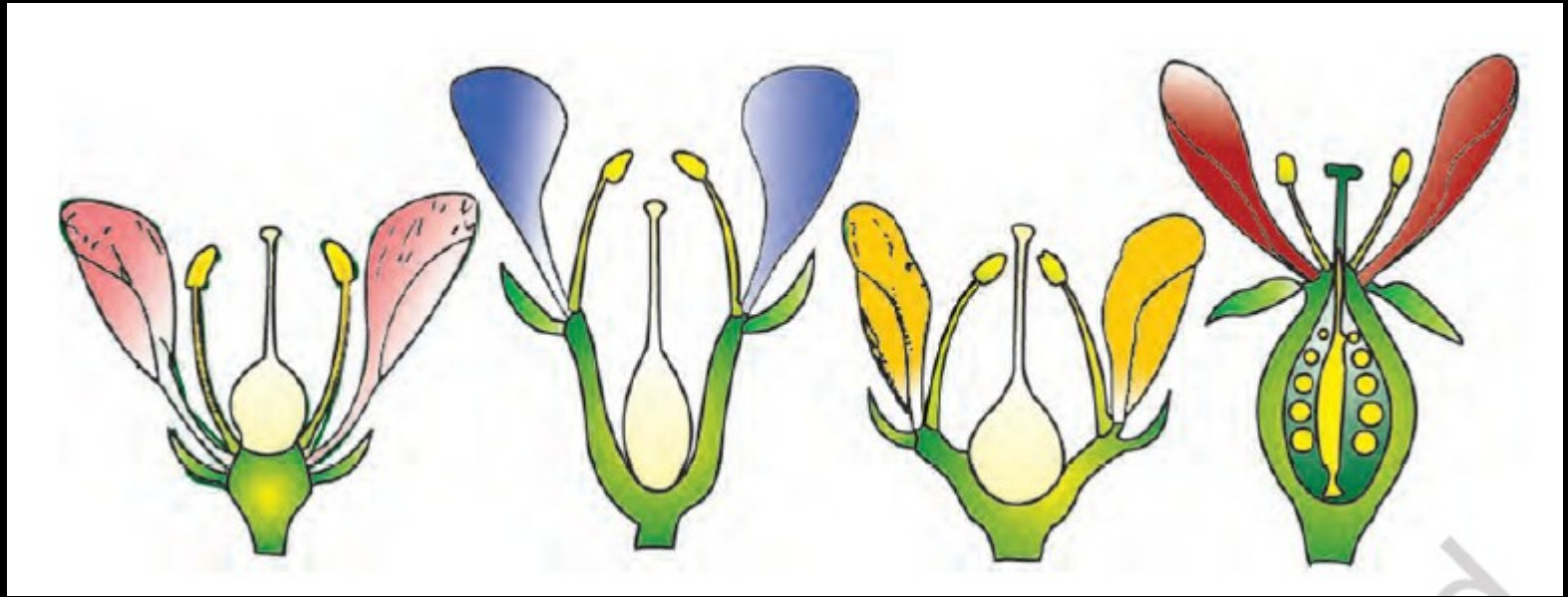

Lamina
Stipule
Petiole
Axillary bud
Leaf base
(a)

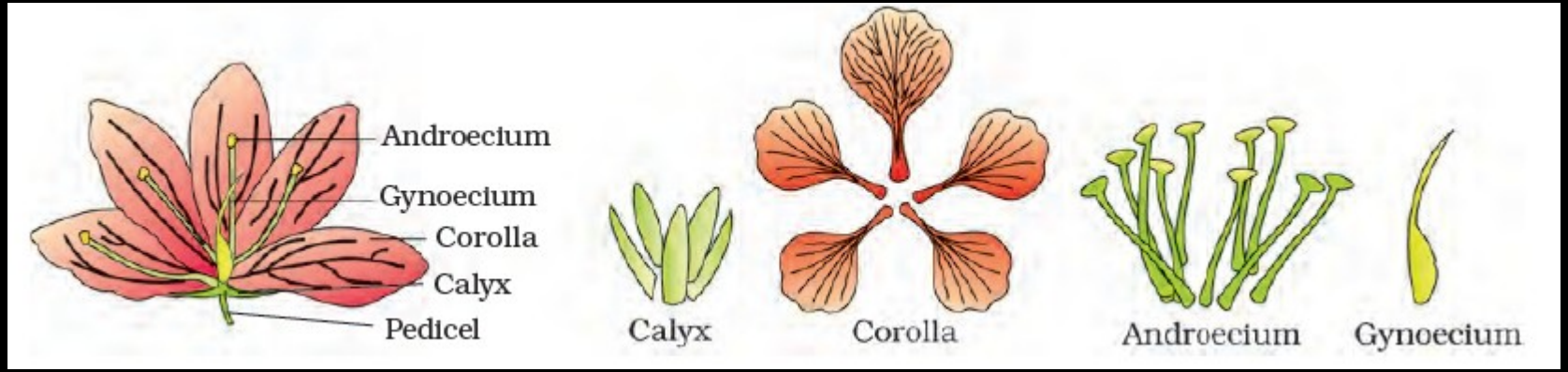

Rachis
(a) Neem
(b) Silk Cotton

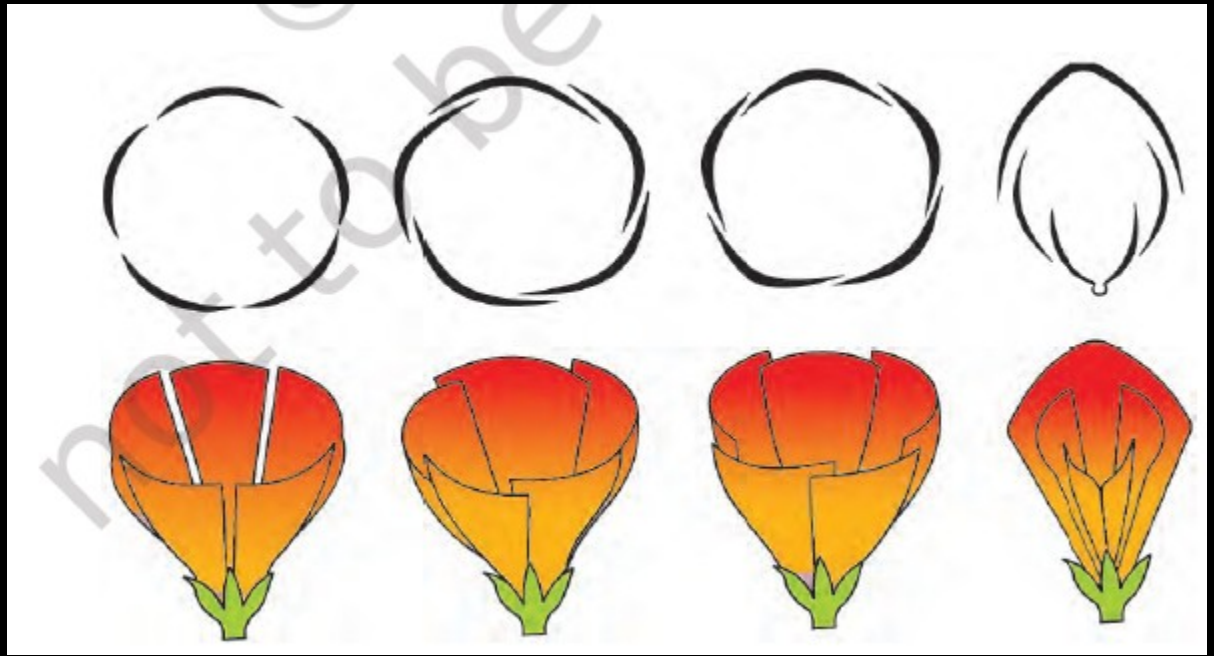

(a) China rose
(b) Guava
(c) Alstonia

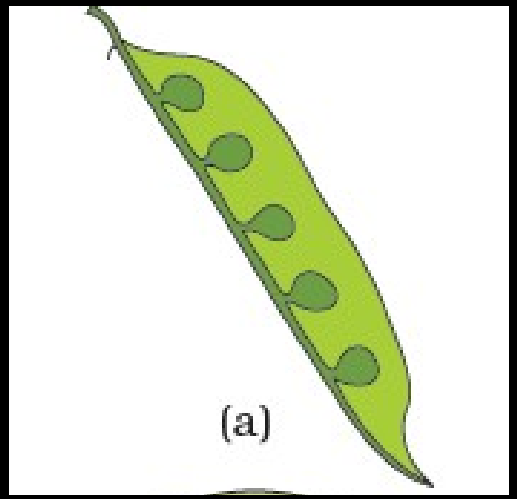

Leaf
tendril
(a) Pea
Leaves
modified
into spines
(b) Cactus
Fleshy
leaves
(c) Onion

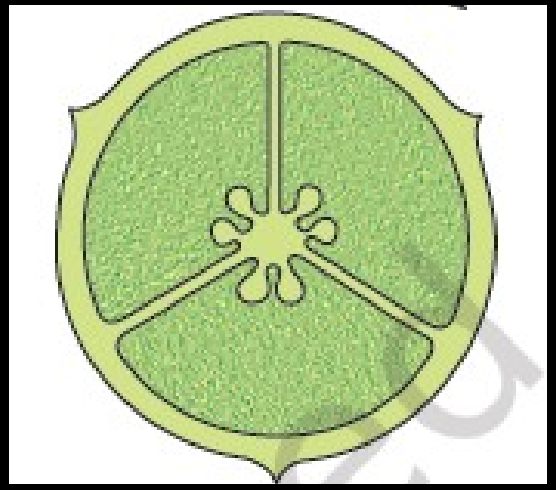


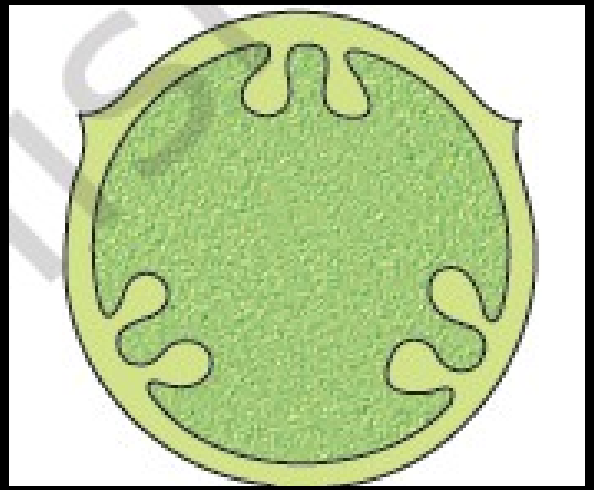


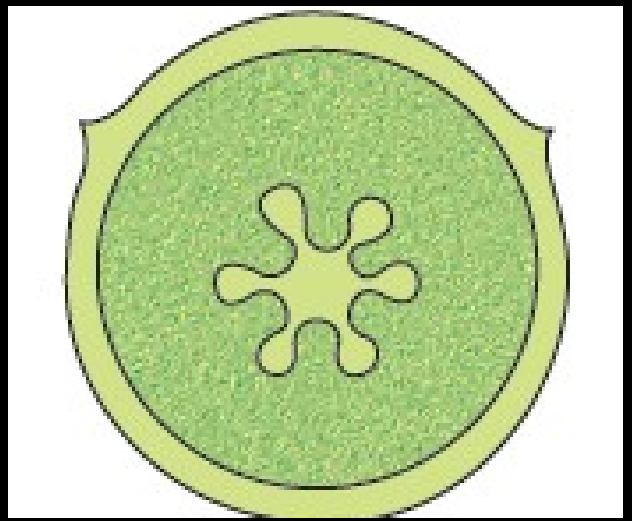

Androecium
Gynoecium
Corolla
Calyx
Pedicel
Calyx
Corolla
Androecium
Gynoecium

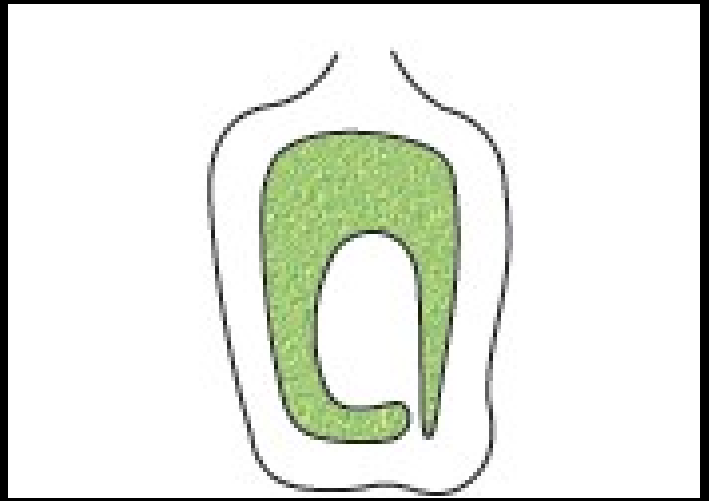


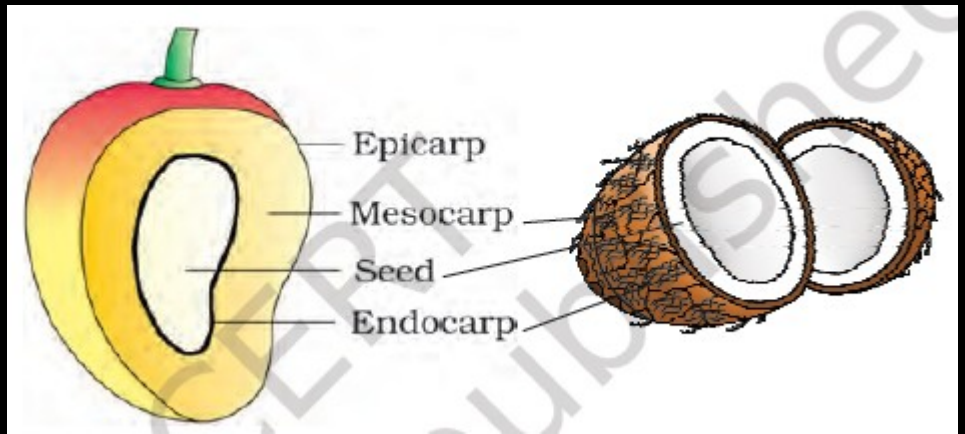

(a)

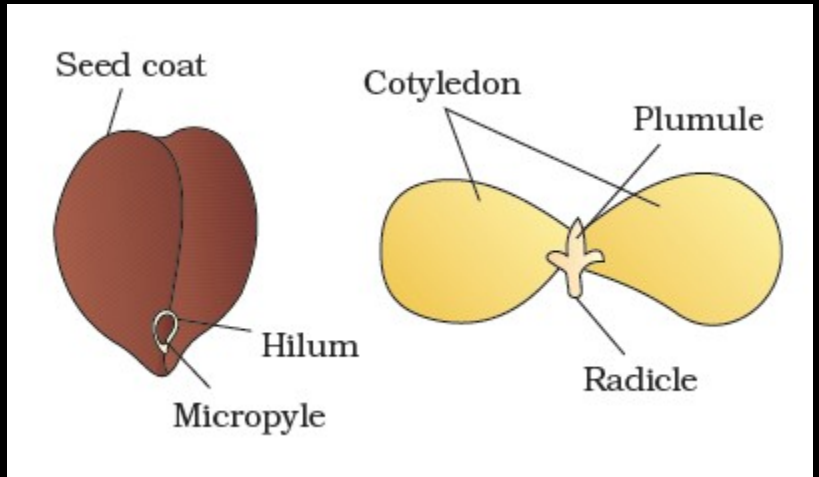


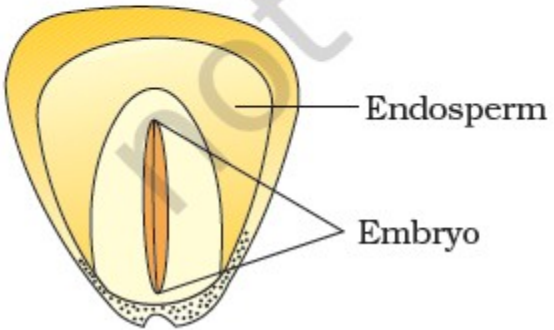


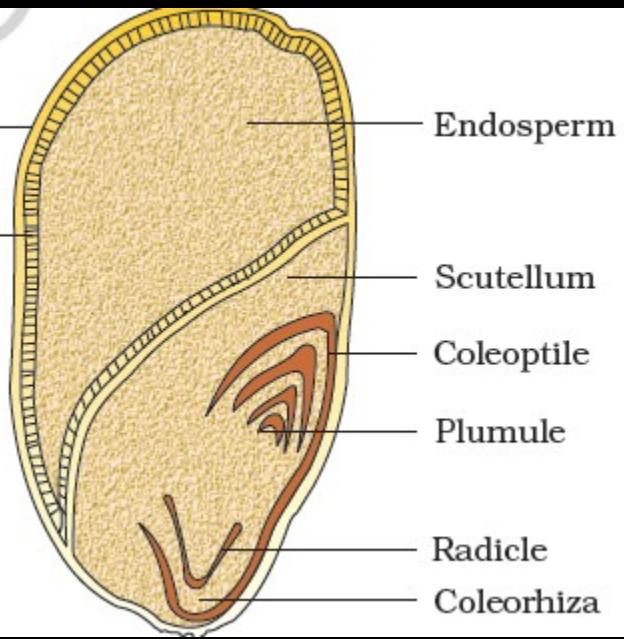


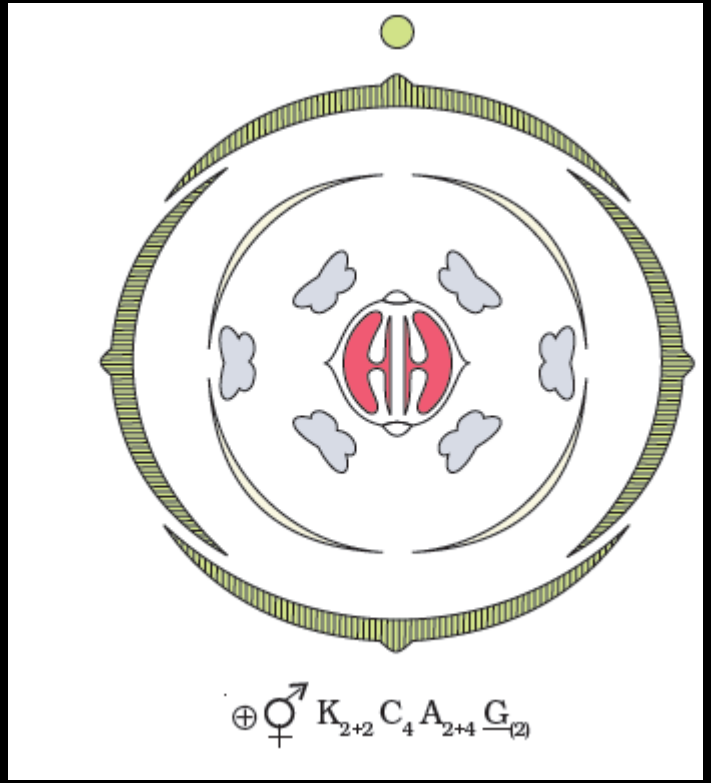



Epicarp
Mesocarp
Seed
Endocarp

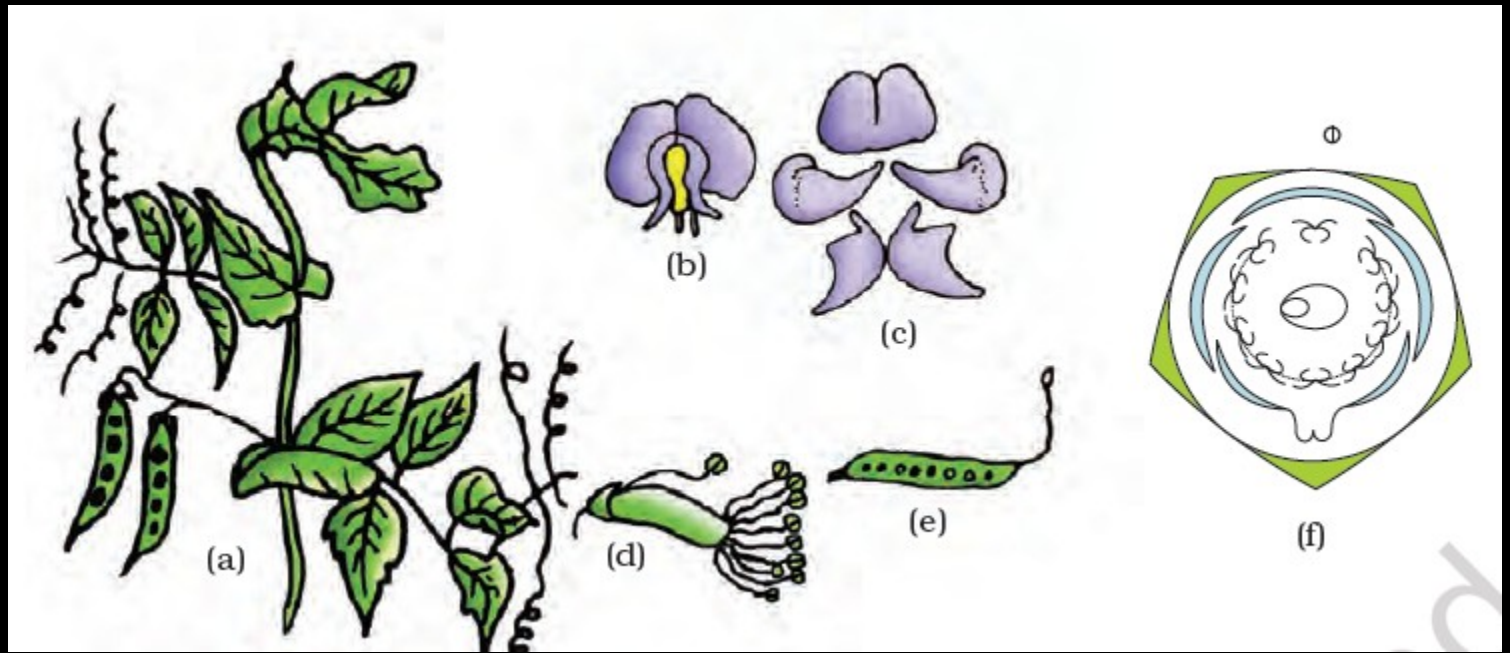

Seed coat
Hilum
Micropyle
Cotyledon
Plumule
Radicle

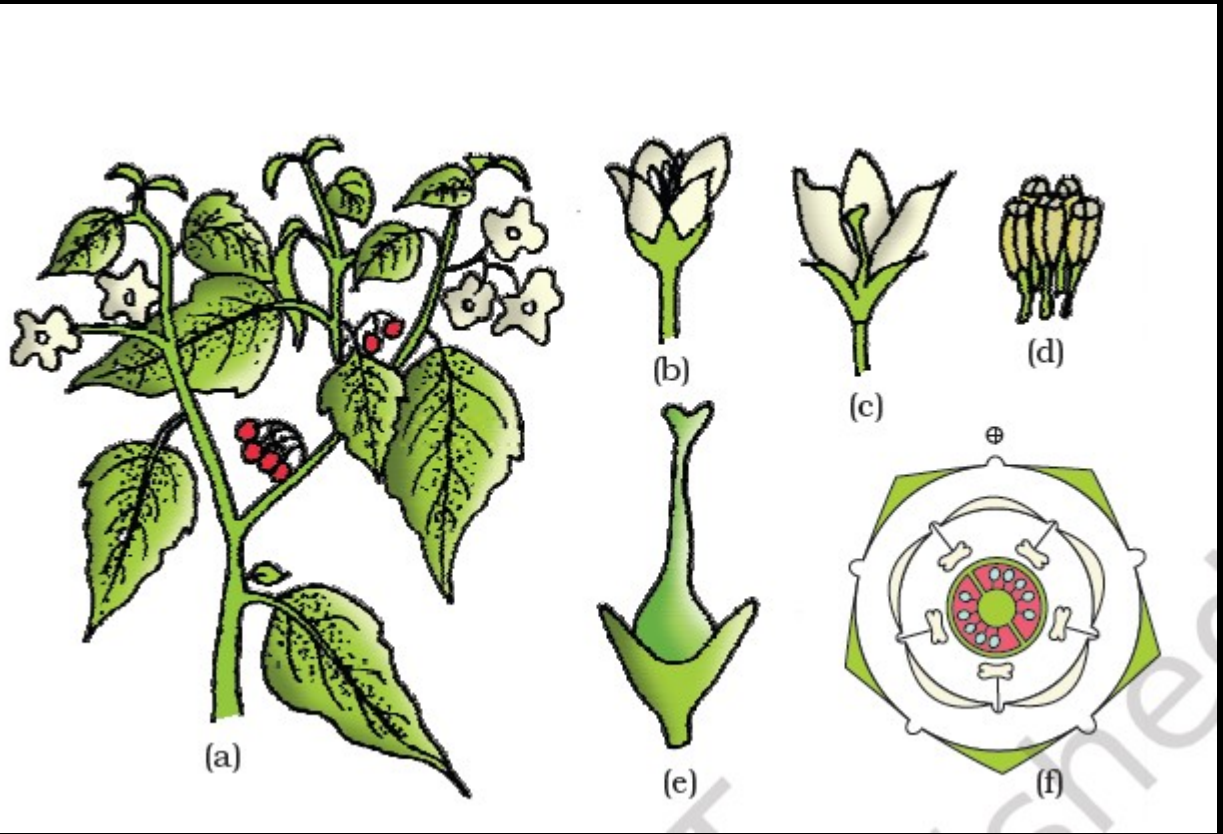



Seed coat & fruit-wall
Aleurone layer
Endosperm
Embryo
Endosperm
Scutellum
Coleoptile
Plumule
Radicle
Coleorhiza



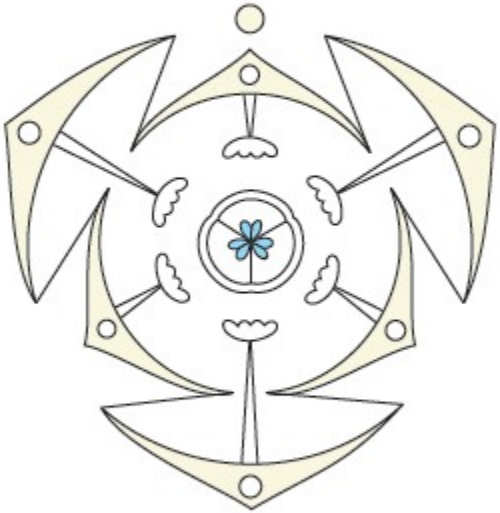
$\oplus \mathrm{K}_{2+2}\,\mathrm{C}_{4}\,\mathrm{A}_{2+4}\,\underline{\mathrm{G}}_{(2)}$


(a)
(b)
(c)
(d)
(e)
(f)


(a)
(b)
(c)
(d)
(e)
(f)

(b)

(c)



(d)

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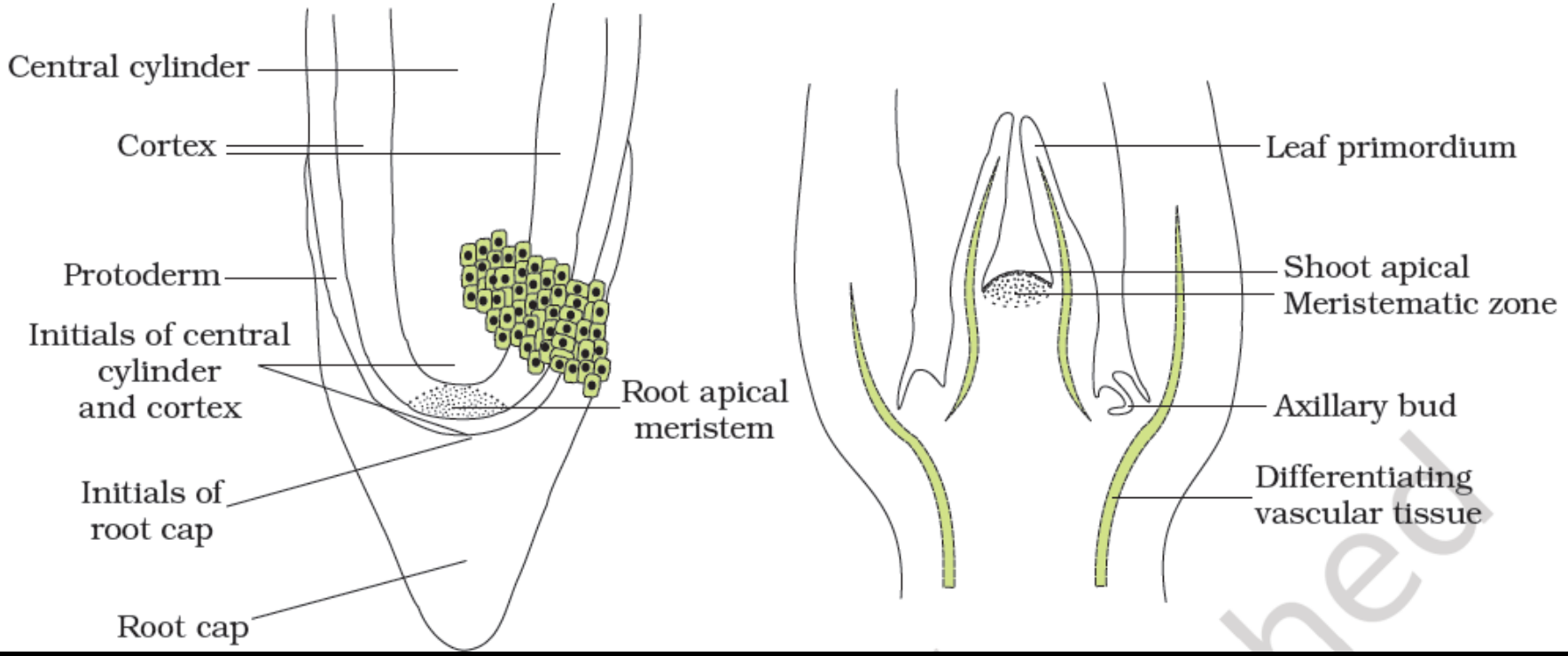
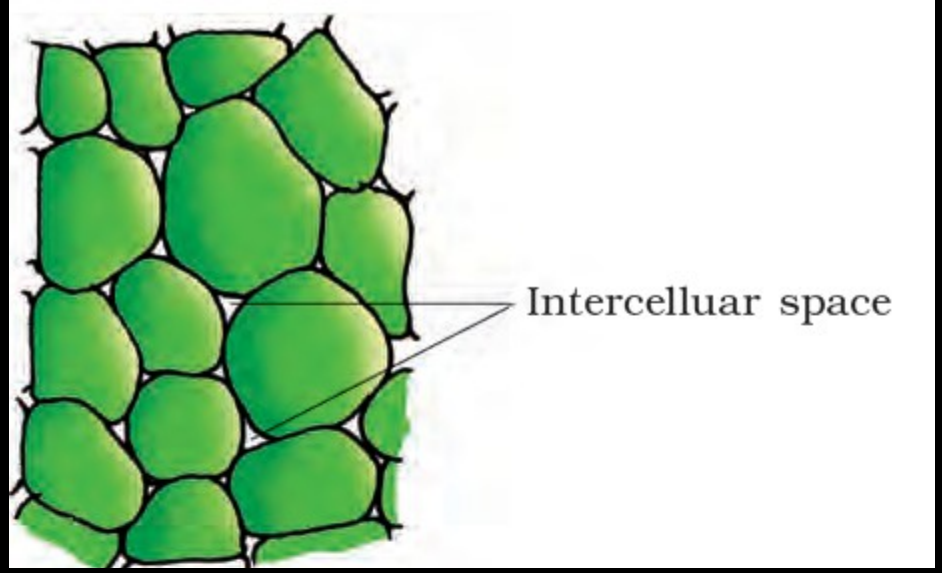
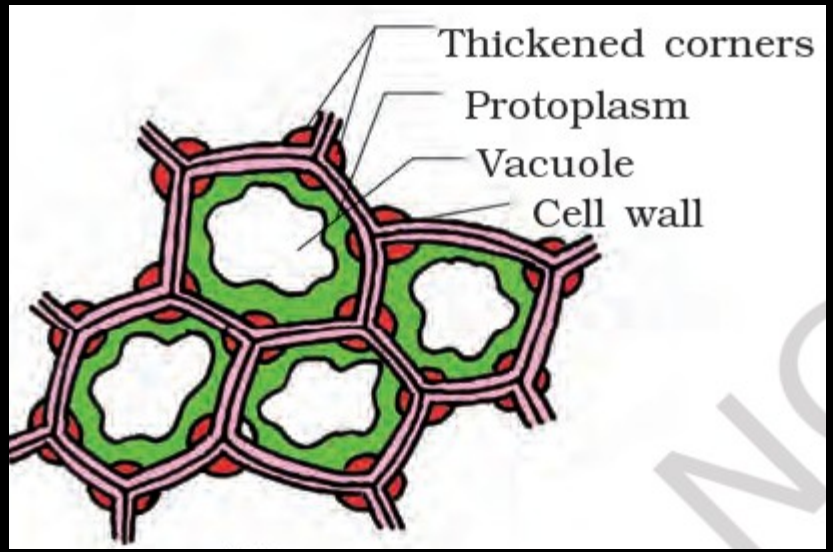
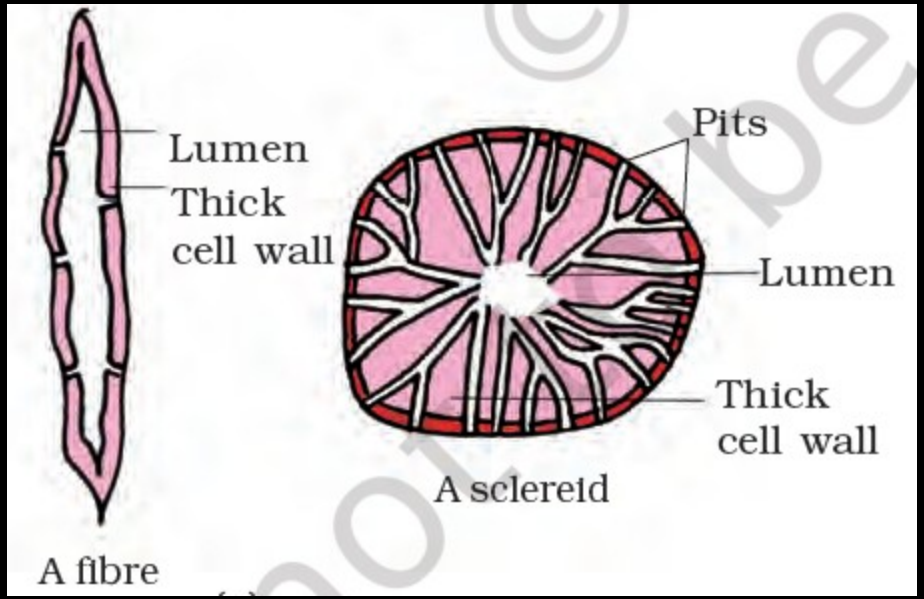
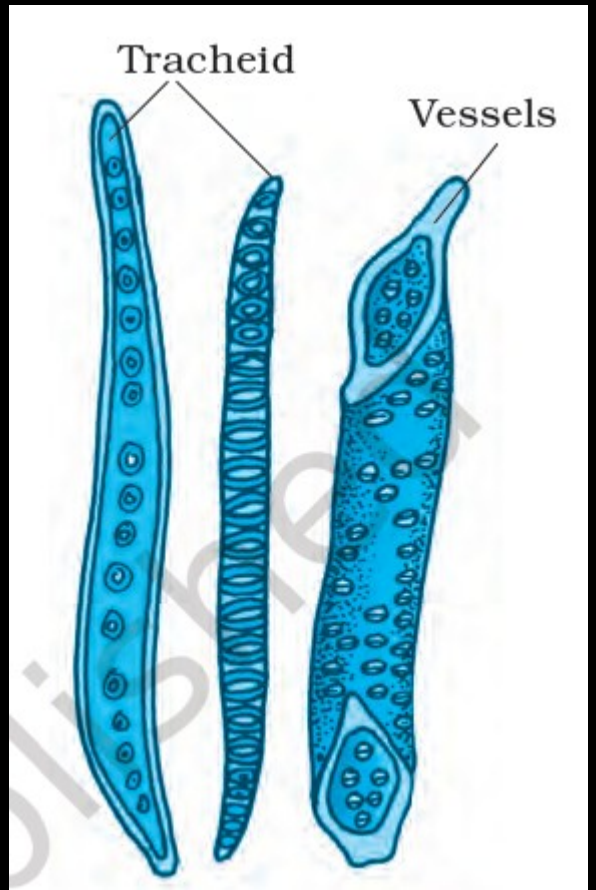
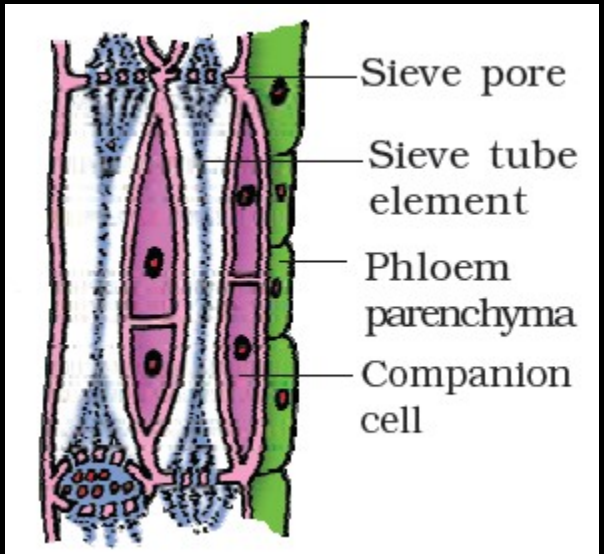

Central cylinder
Cortex
Protoderm
Initials of central cylinder and cortex
Root apical meristem
Initials of root cap
Root cap
Leaf primordium
Shoot apical Meristematic zone
Axillary bud
Differentiating vascular tissue

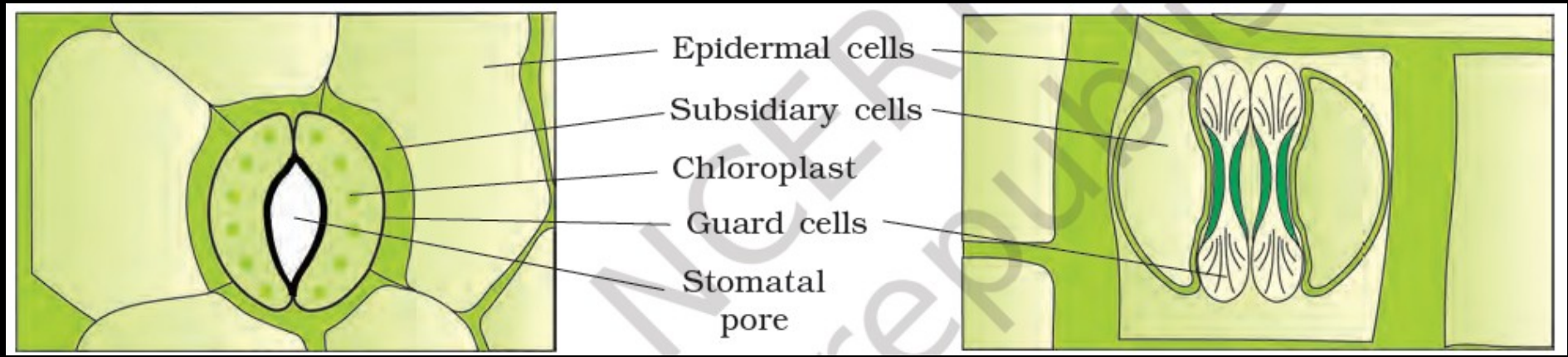

Intercelluar space

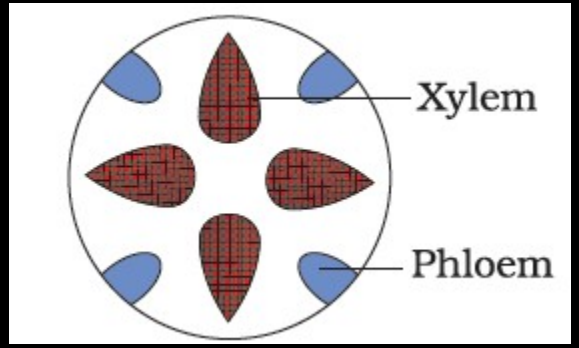

Thickened corners
Protoplasm
Vacuole
Cell wall

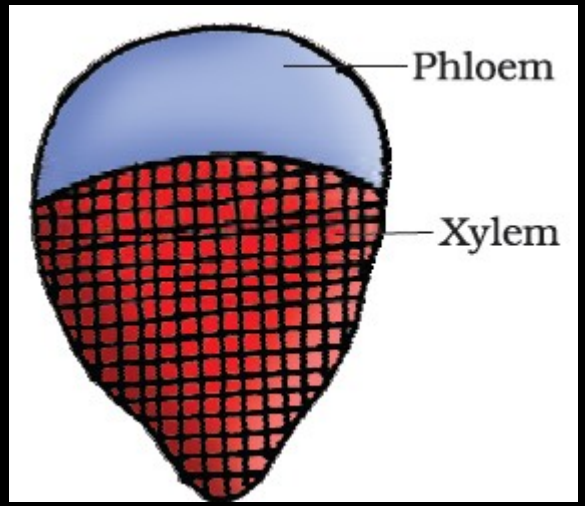

Lumen
Thick
cell wall
A fibre
Pits
Lumen
Thick
cell wall
A sclereid

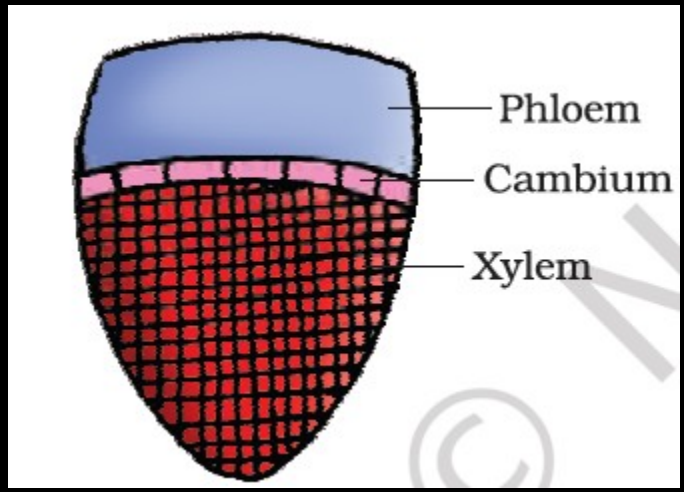

Tracheid
Vessels

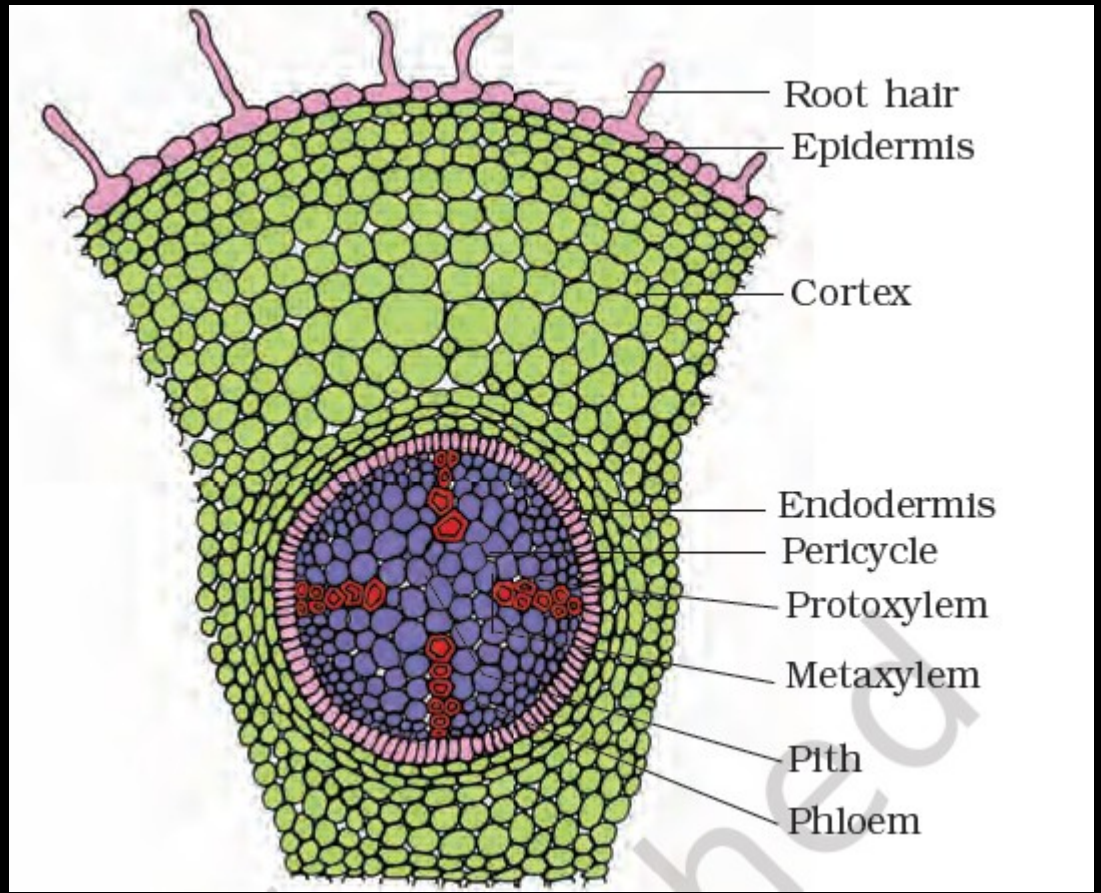

Sieve pore
Sieve tube element
Phloem parenchyma
Companion cell

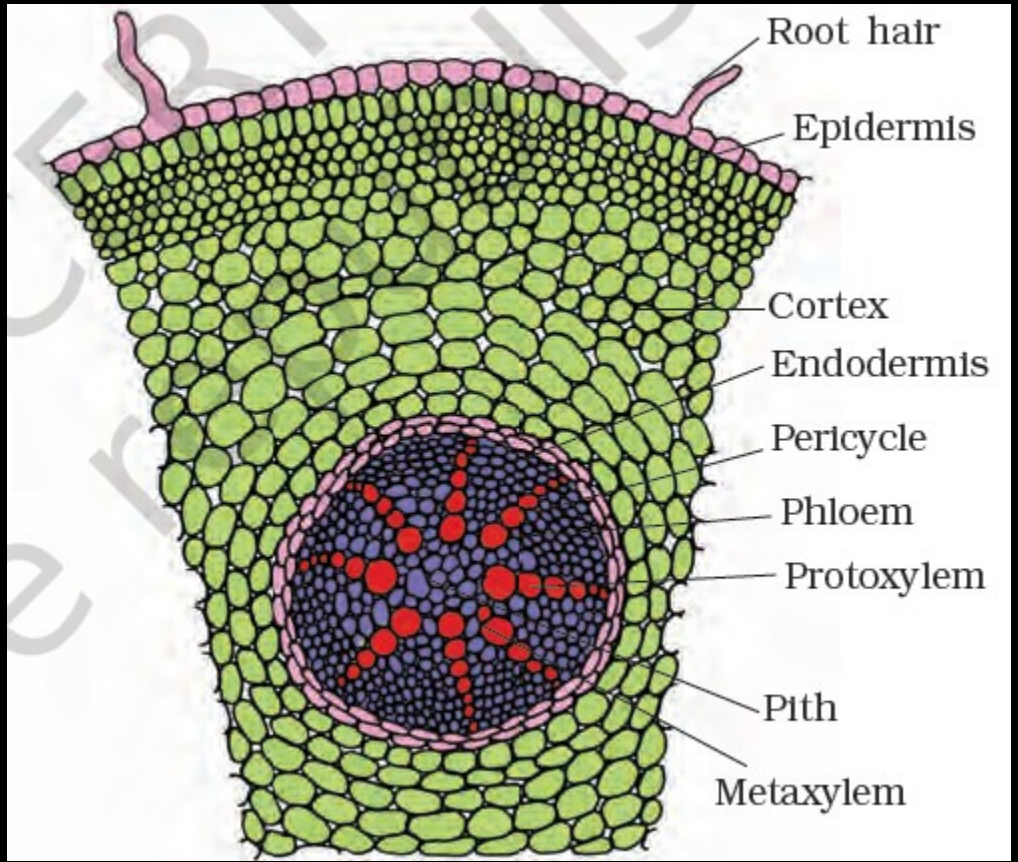

Epidermal cells
Subsidiary cells
Chloroplast
Guard cells
Stomatal pore

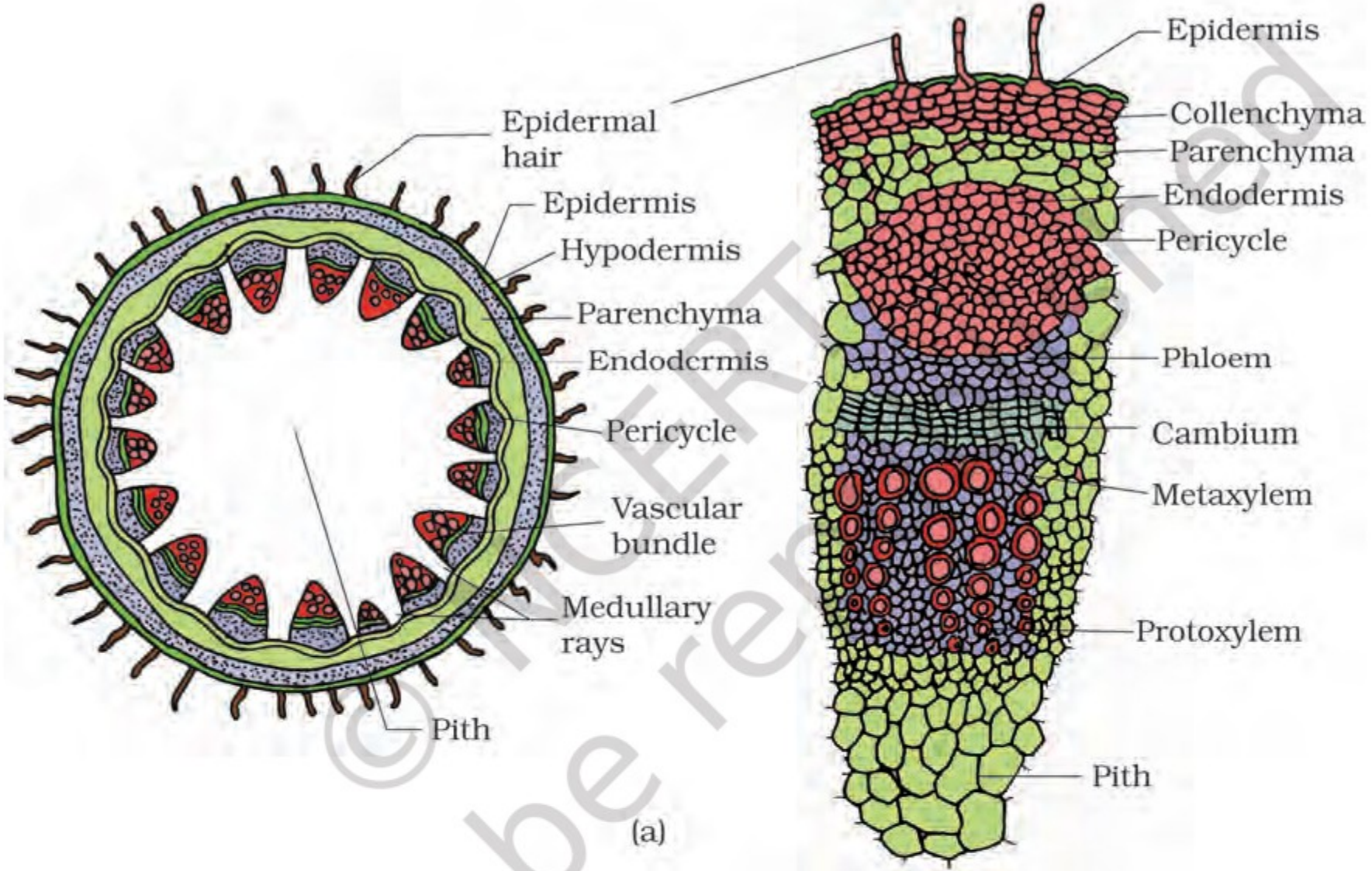

Xylem
Phloem

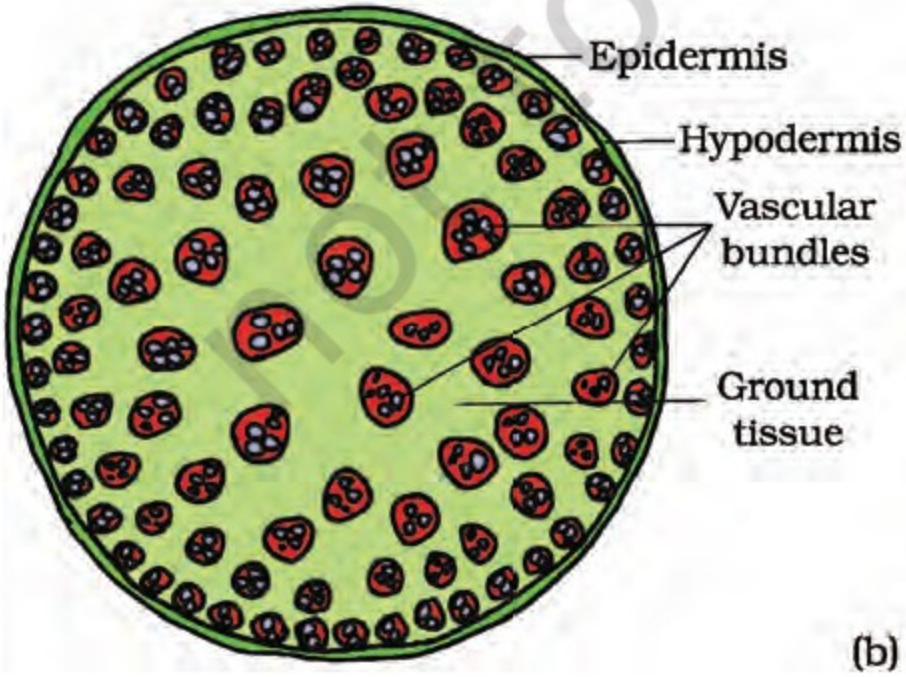

Phloem
Xylem


Phloem
Cambium
Xylem

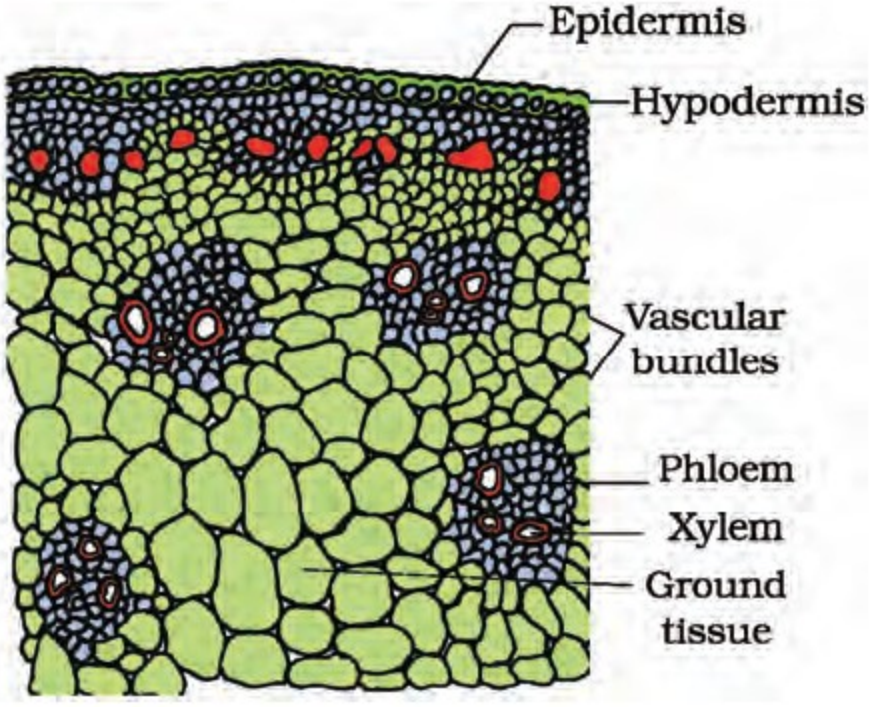

Root hair
Epidermis
Cortex
Endodermis
Pericycle
Protoxylem
Metaxylem
Pith
Phloem

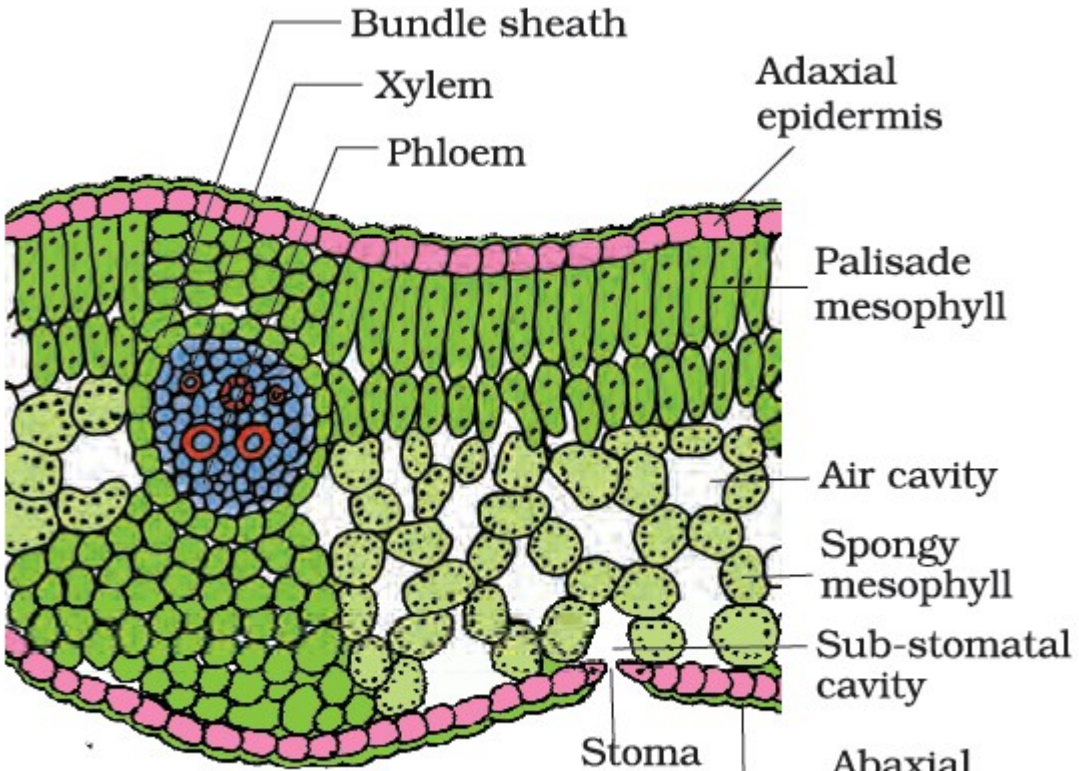

Root hair
Epidermis
Cortex
Endodermis
Pericycle
Phloem
Protoxylem
Pith
Metaxylem

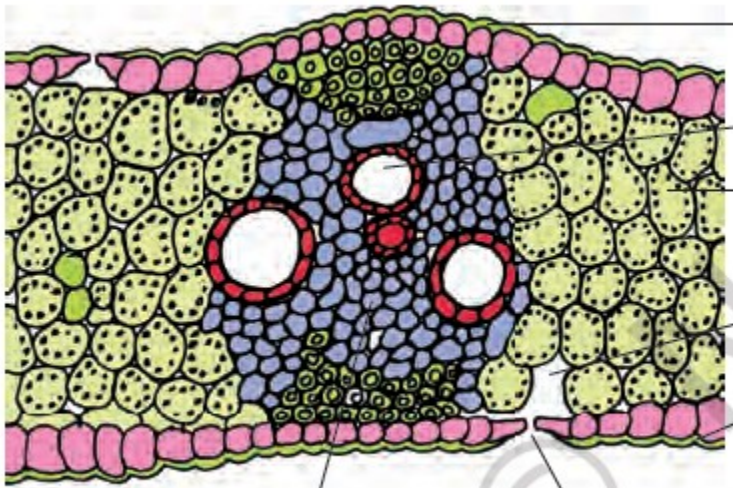

Epidermal hair
Epidermis
Hypodermis
Parenchyma
Endodermis
Pericycle
Vascular bundle
Medullary rays
Pith
(a)
Epidermis
Collenchyma
Parenchyma
Endodermis
Pericycle
Phloem
Cambium
Metaxylem
Protoxylem
Pith

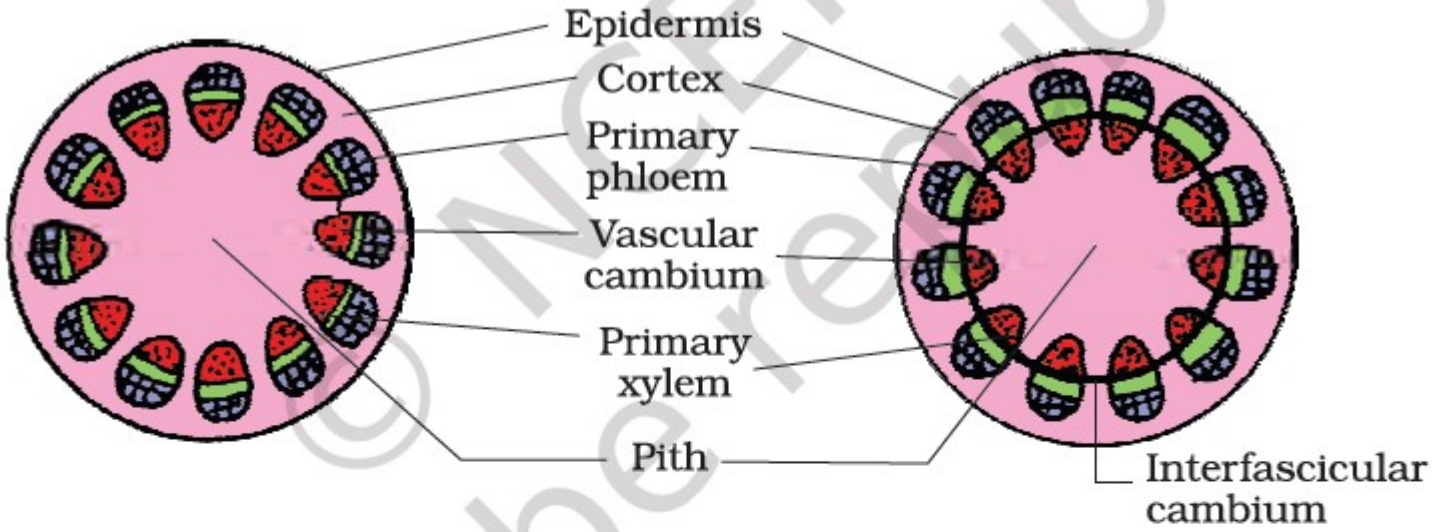

Epidermis
Hypodermis
Vascular bundles
Ground tissue

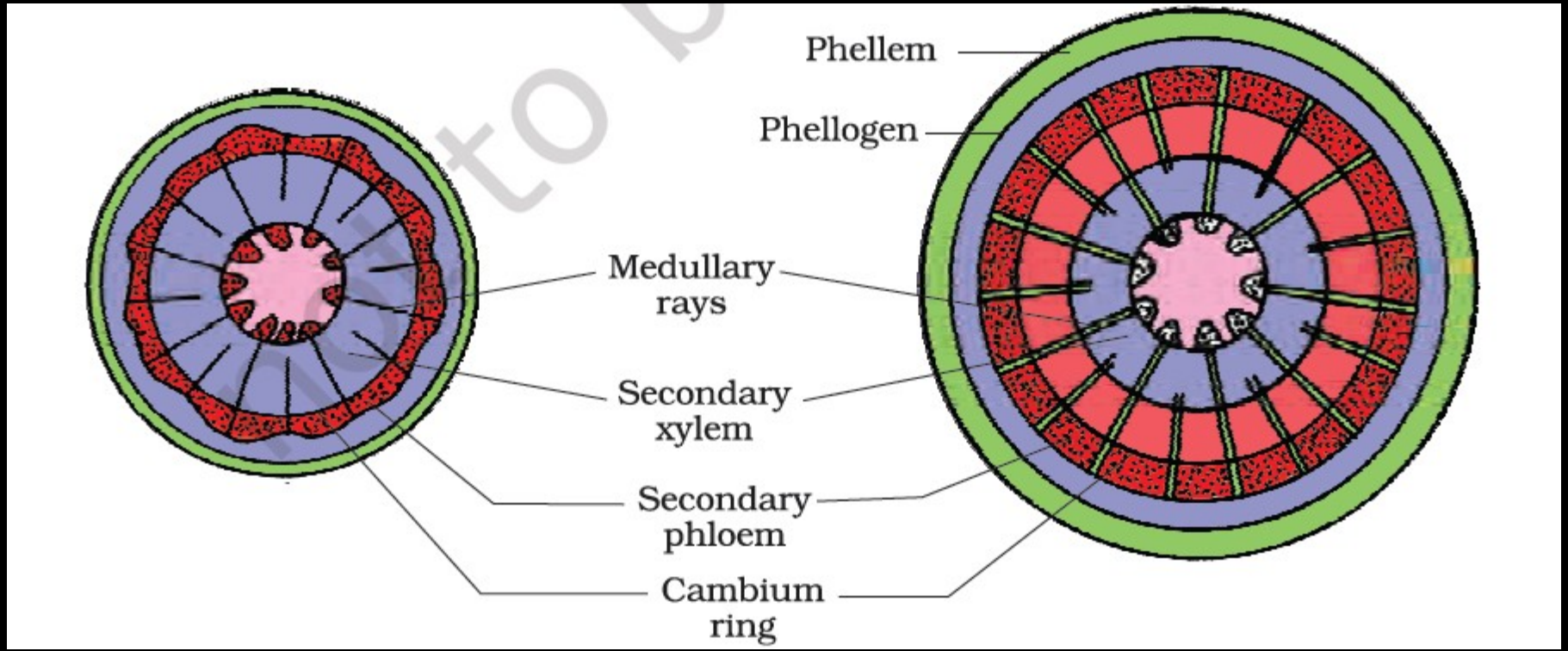
(b)

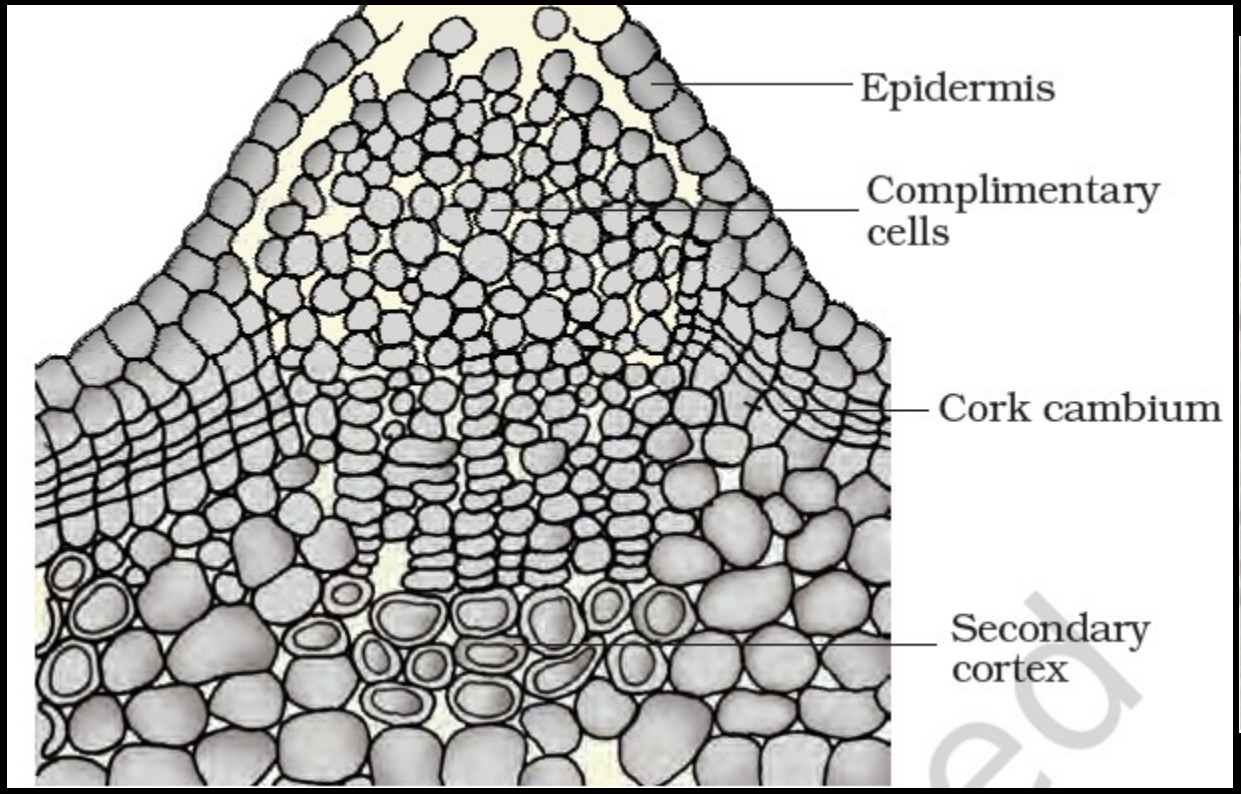

Epidermis
Hypodermis
Vascular bundles
Phloem
Xylem
Ground tissue

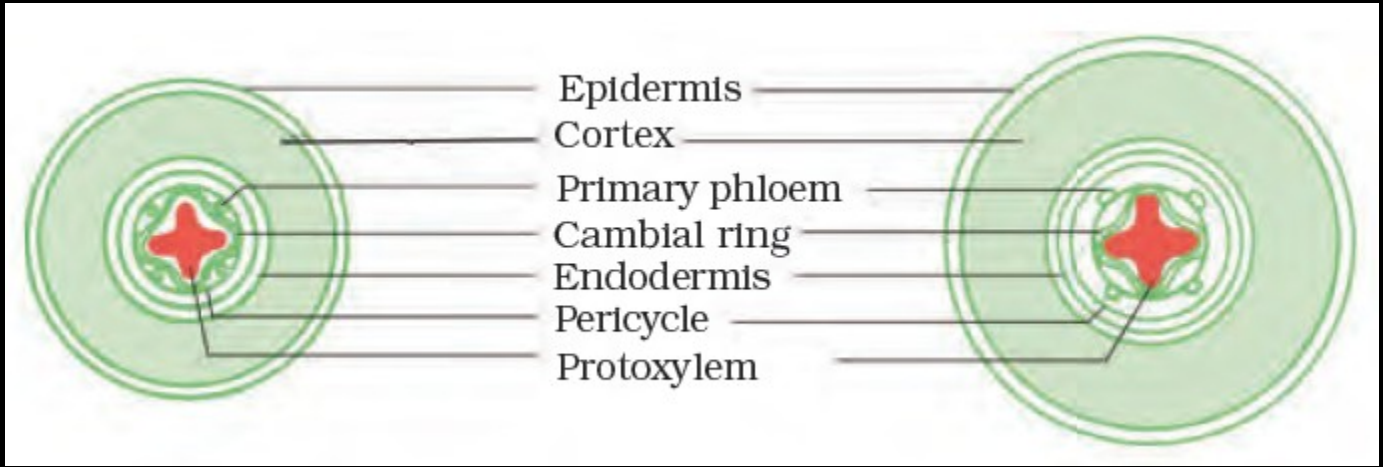

Bundle sheath
Xylem
Phloem
Adaxial epidermis
Palisade mesophyll
Air cavity
Spongy mesophyll
Sub-stomatal cavity
Stoma
Abaxial epidermis
(a)

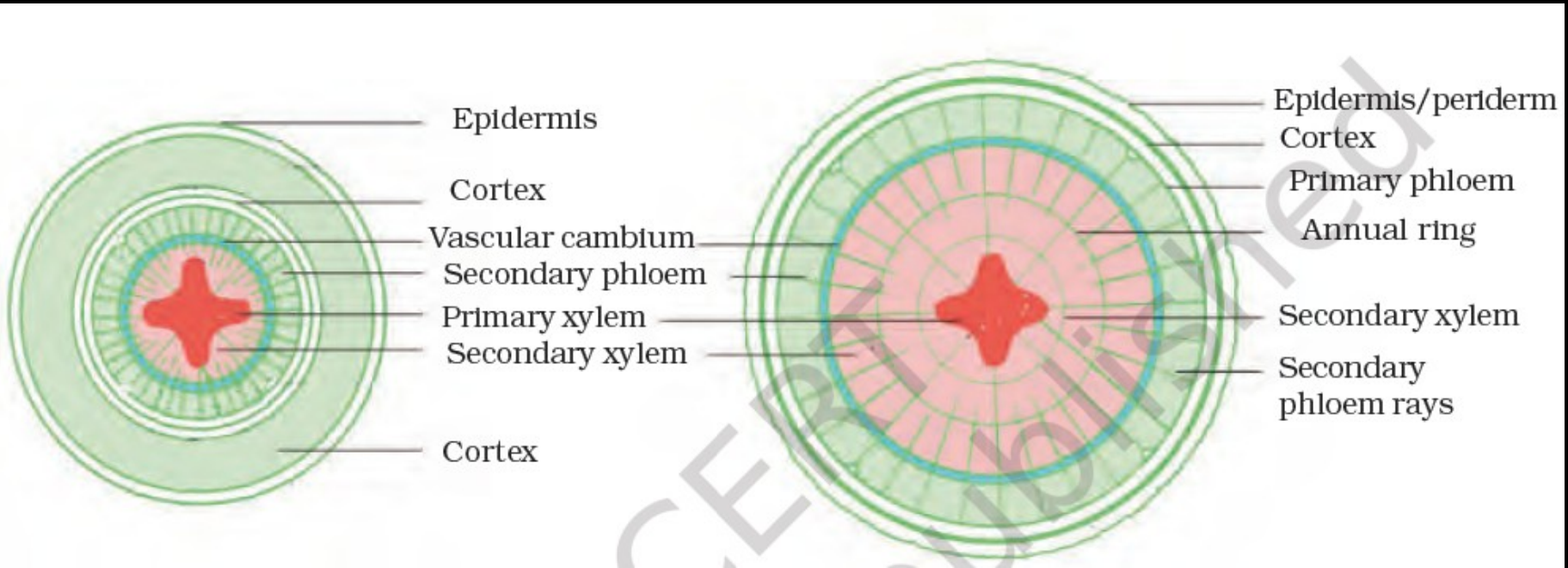

Adaxial epidermis
Xylem
Mesophyll
Sub-stomatal cavity
Abaxial epidermis
Stoma
Phloem


Epidermis
Cortex
Primary phloem
Vascular cambium
Primary xylem
Pith
Interfascicular cambium


Phellem
Phellogen
Medullary rays
Secondary xylem
Secondary phloem
Cambium ring


Epidermis
Complimentary cells
Cork cambium
Secondary cortex


Epidermis
Cortex
Primary phloem
Cambial ring
Endodermis
Pericycle
Protoxylem


Epidermis
Cortex
Vascular cambium
Secondary phloem
Primary xylem
Secondary xylem
Cortex
Epidermis/periderm
Cortex
Primary phloem
Annual ring
Secondary xylem
Secondary phloem rays

Photoperiodism

Flowering is an annual rhythm controlled by exogenous (external) factors (many plants only flower at a particular time of the year). This response to the changing day-length (photo-period) is known as photoperiodism.

Plants can respond to changing day length in three different possible ways:

Note: while many plants recognise seasonal changes by changing photoperiod (day length), this is not always the sole determining factor. Many plants only flower when they are exposed to colder winter temperatures. This process is known as **vernalisation**.

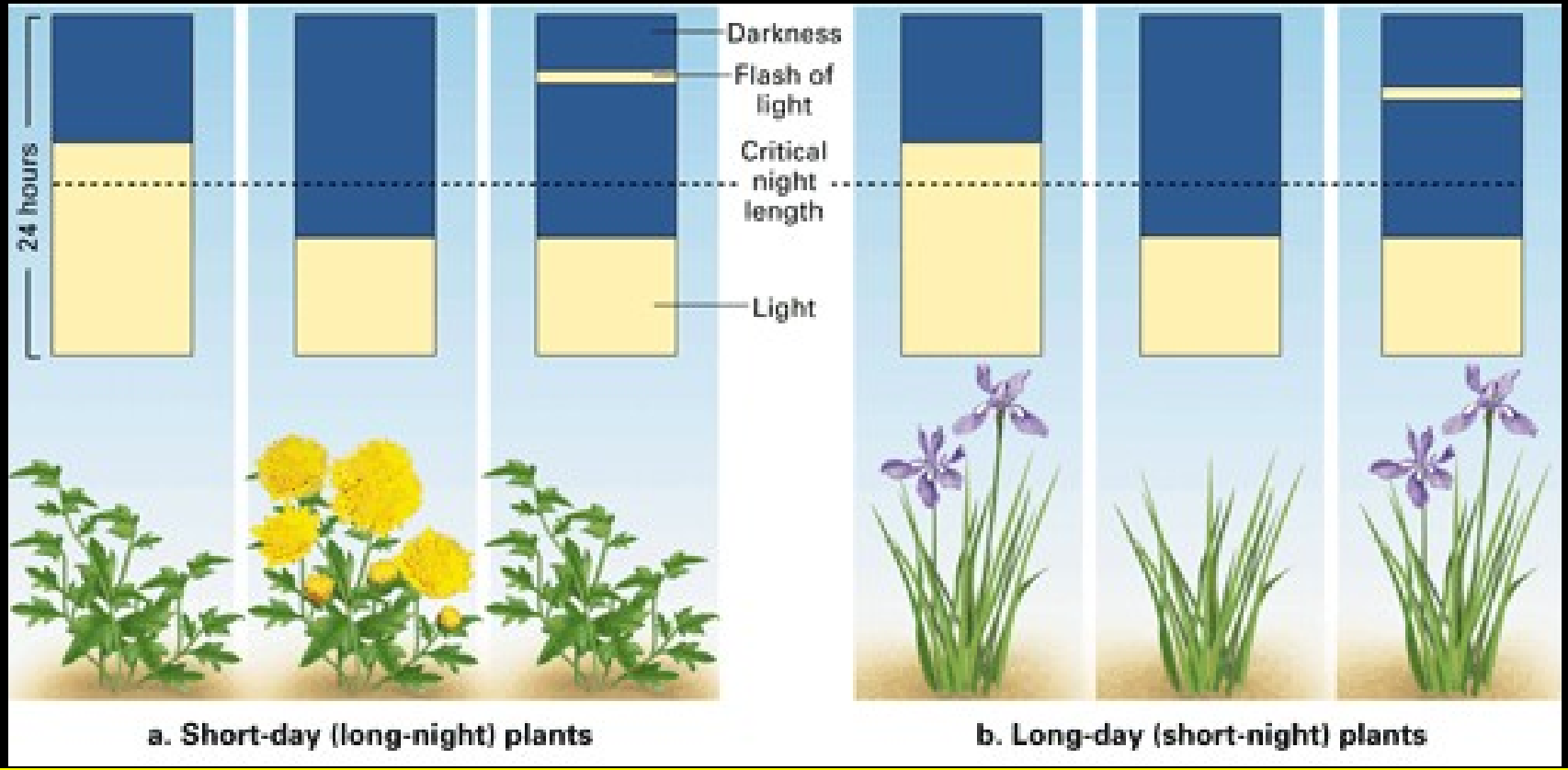
Long Day Plants flower when the photoperiod (day) exceeds a critical day length.

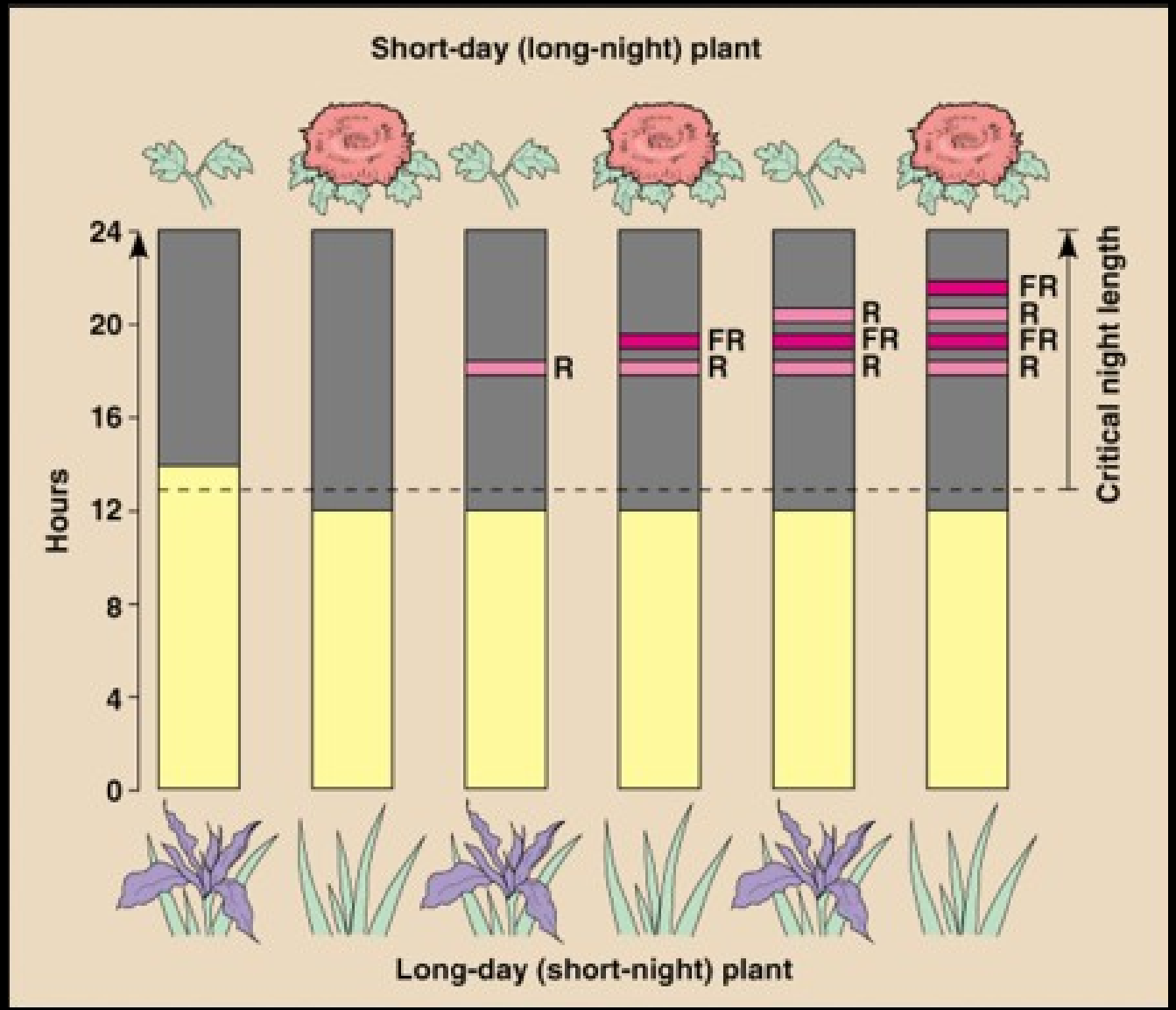
Short Day Plants flower when the photoperiod is less than the critical day length.

However, it has actually been discovered that it's the **night length**, not the day length that controls flowering.

The period of uninterrupted darkness (critical night length) is what actually controls flowering. Therefore…

- Long Day Plants are actually Short Night Plants
- Short Day Plants are actually Long Night Plants


24 hours
Darkness
Flash of light
Critical night length
Light
a. Short-day (long-night) plants
b. Long-day (short-night) plants


Short-day (long-night) plant
24
20
16
12
8
4
0
Hours
R
FR
R
R
FR
R
FR
R
FR
R
Critical night length
Long-day (short-night) plant