Plant Growth

Morphogenesis

Plant Embryonic Development
Embryogenesis

Morphogenesis

Morphogenesis is a continuous process starting with germination followed by vegetative growth stage , reproductive stage (flowering) and then senescence.

Morphogenesis, the shaping of an organism by embryological processes of differentiation of cells, tissues, and organs and the development of organ systems according to the genetic “blueprint” of the potential organism and environmental conditions.

Plant Embryonic Development

Plant embryonic development, or plant embryogenesis is a process that occurs after the fertilization of an ovule to produce a fully developed plant embryo. This is a relevant stage in the plant life cycle that is followed by dormancy and germination. The zygote produced after fertilization must undergo various cellular divisions and differentiations to become a mature embryo. An end stage "embryo" has five major components including the shoot apical meristem, hypocotyl, root meristem, root cap, and cotyledons. Plant embryonic development results in an immature form of the plant, lacking most structures like leaves, stems, and reproductive structures.

Embryogenesis and seed development

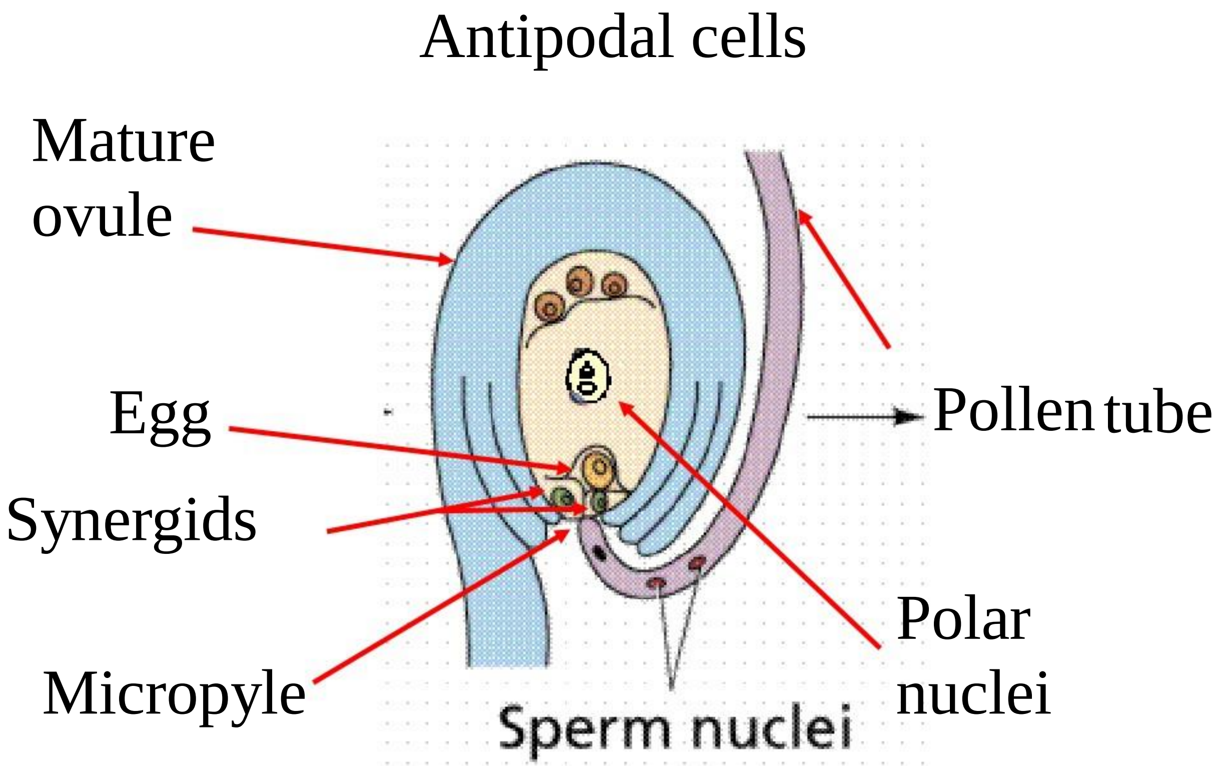
Two stages :-

Embryo development:

1. Establishment of patterns.
2. Establishment of meristem regions.

Endosperm development: production of storage materials/signals and preparation for embryo development and seed germination.

Embryo development / Double fertilization



- Begin with the fertilized egg.
- Diploid.
- Establishment of patterns and meristem regions.

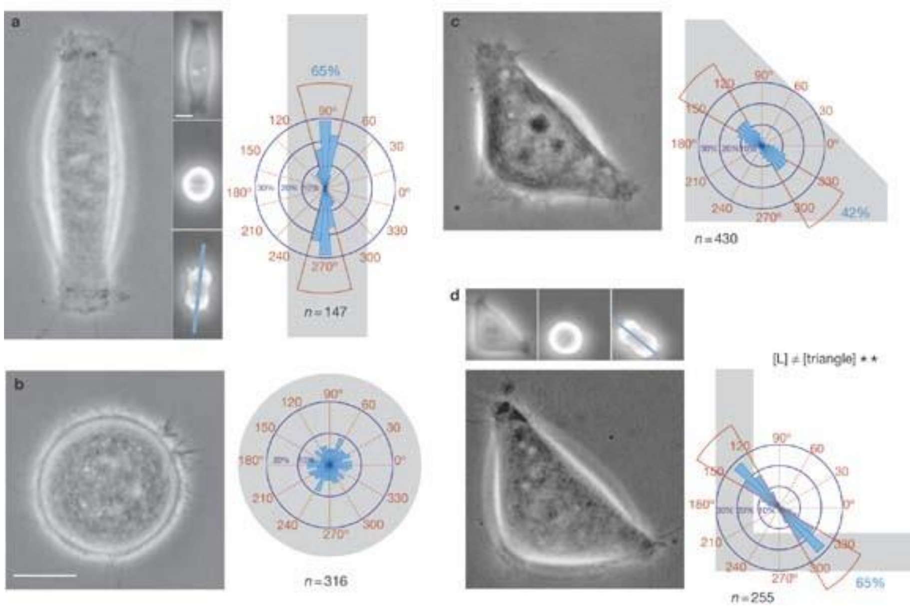
Double fertilization involves two sperm cells; one fertilizes the egg cell to form the zygote, while the other fuses with the two polar nuclei that form the endosperm.

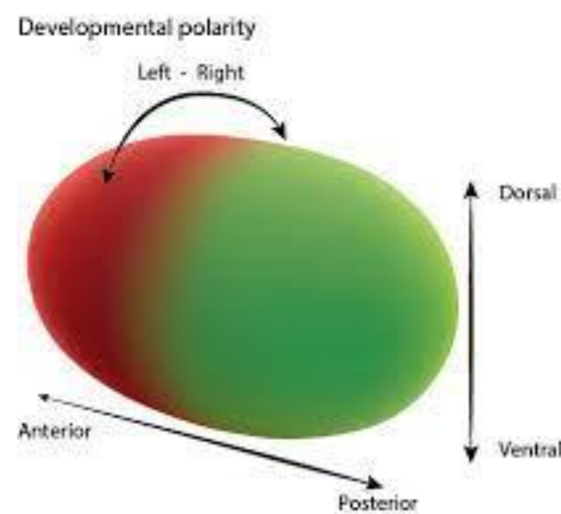
Antipodals serve the function of providing nutrition to the egg cell and zygote later.

Synergids help the entry of the male gamete into the embryo sac and the fusion of male gamete with the egg

The cell division axis determines the future positions of daughter cells and is therefore critical for cell fate.

Cell polarization, defined as the asymmetric distribution of proteins, organelles, and cytoplasm.

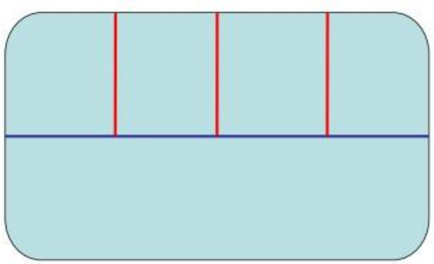


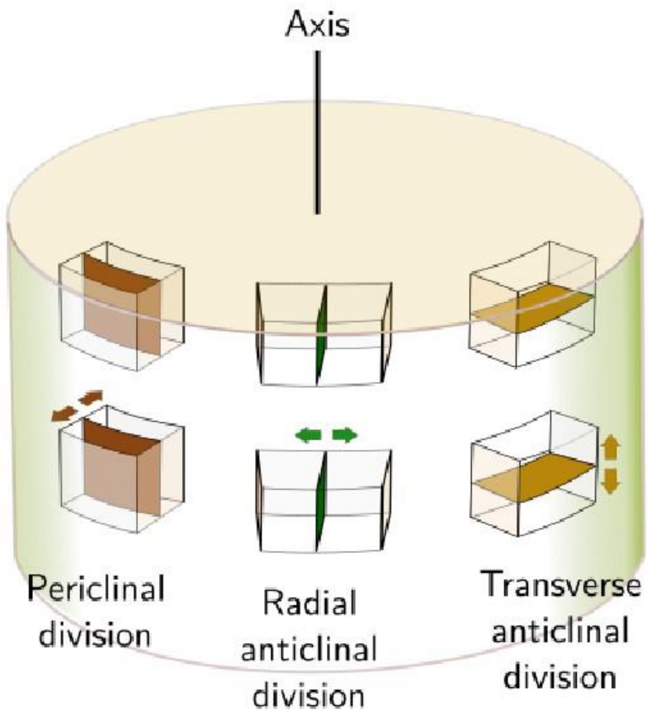


Precisely controlled cell fate

Precisely controlled cell fate

Since plant cells can not move, strictly oriented cell division determines patterning of the embryo.

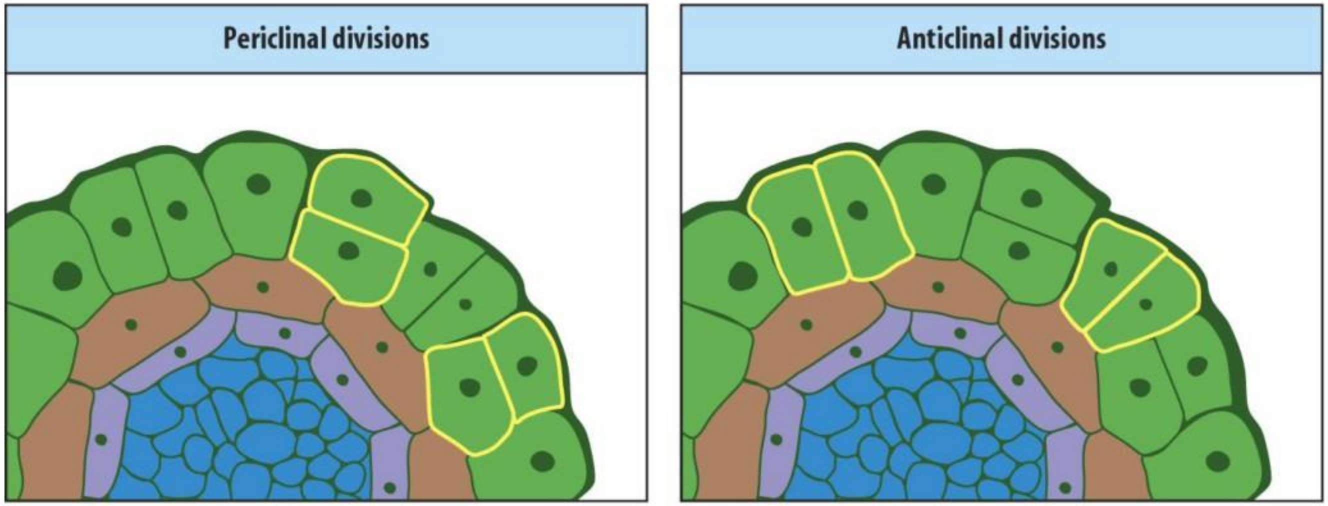


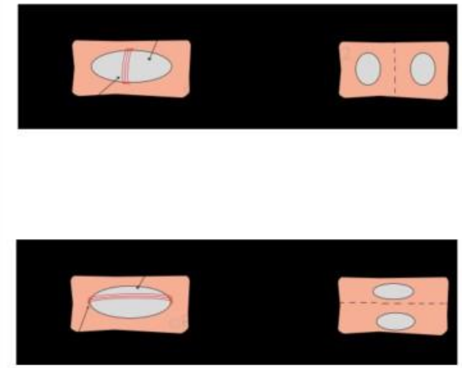


Main orientation of the plane of cell division considering the surface of the organ where they cells are located.

Periclinal: parallel to the surface.
Radial anticlinal: perpendicular to the surface and parallel to the axis.
Transverse anticlinal: perpendicular to both the surface and the axis.

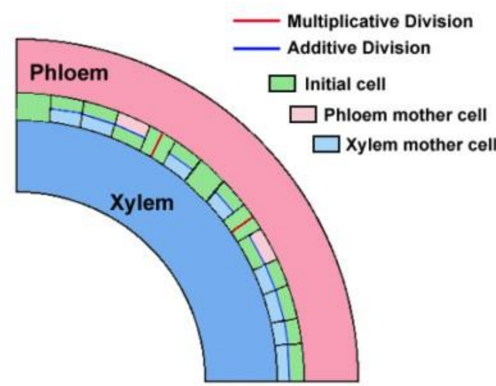
Periclinal and anticlinal divisions of meristems





Periclinal (radial) divisions give new tissue layers.

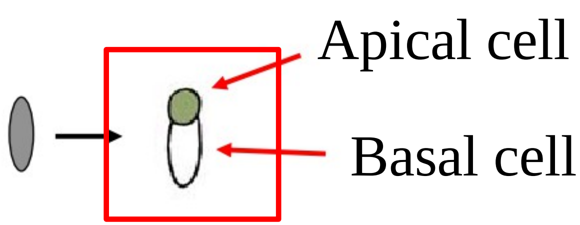
Anticlinal divisions increase the number cells in a layer.



Steps for embryo development

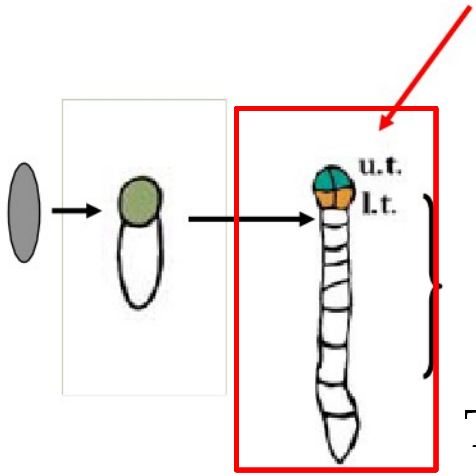
1. Elongation of the fertilized egg

2. The first cell division is asymmetric.
   The apical (top) cell receives most of the cytoplasm and is active in protein synthesis. The apical cell goes on to make the proper embryo
   The basal cell and its descendants are highly vacuolated. They form the suspensor to connect to the maternal tissue.



The **suspensor** is a terminally differentiated embryonic region that connects the embryo to surrounding tissues during early seed development.

3. The octant stage

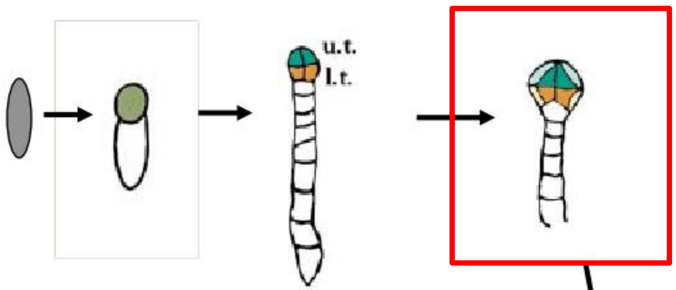


The apical cell divides twice Transversely (Periclinal) and once longitudinally (Anticlinal) to create a sphere of eight cells, an octant.

The basal cell divide transversely (Periclinal) to create a file of cells, suspensor

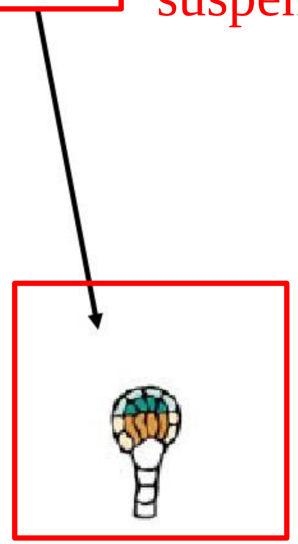
8

4. Dermatogen stage



- Anticlinal division, establish protodermal cells:
- Form hypophysis

suspensor cells undergo programmed cell death

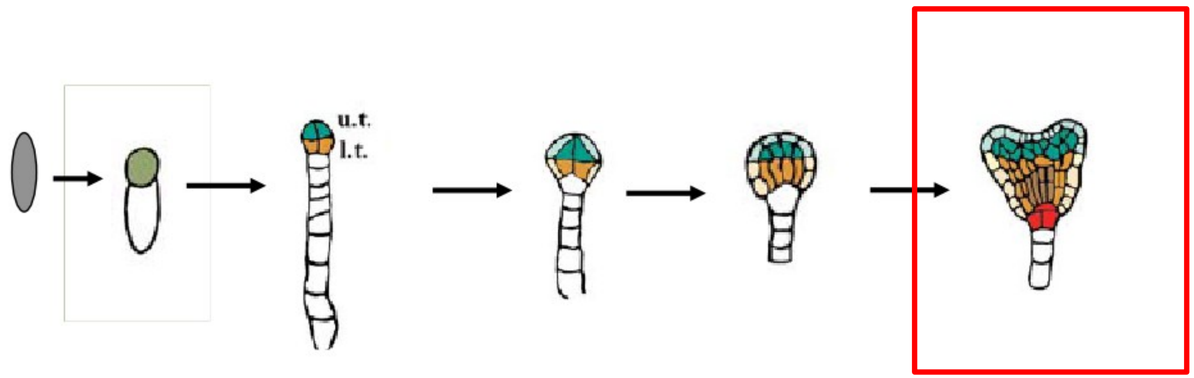


5. Globular stage

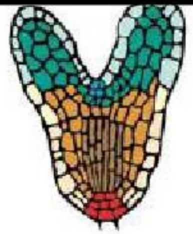
The inner cells divide anticlinally and periclinally, endowing the embryo <u>an recognizable axis</u>.

6. Triangular stage

- Apical domain: generate two symmetrically positioned cotyledon primordia
- Basal domain:
  Form a radially patterned cylinder /
  Initiate root apical meristem from hypophysis

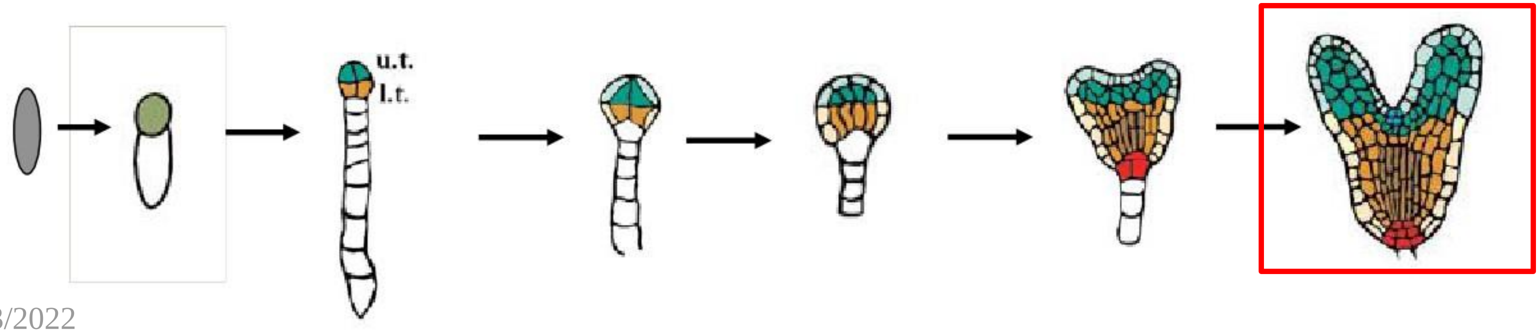


7. Heart stage



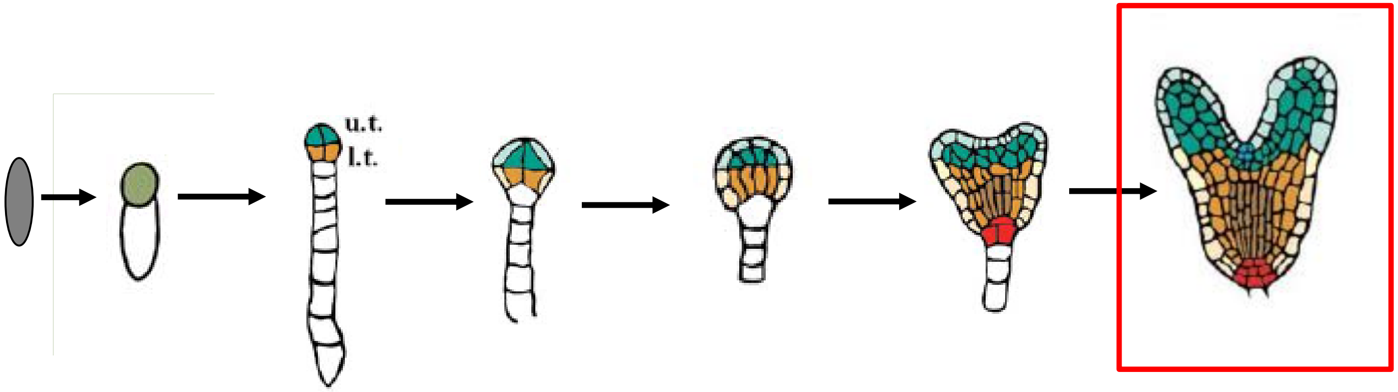
- Apical domain :
  Cotyledon outgrowth
  Establishing shoot apical meristem (SAM)
- Basal domain :
  Establishing shoot axis
  Establishing root apical meristem (RAM).

- Establishing basic tissue types: cortex, perivascular tissue, and protoderm
- Suspensor cells undergo programmed cell death



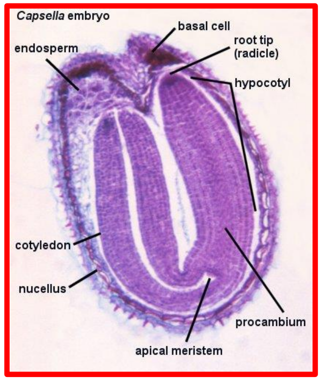
8. Torpedo stage

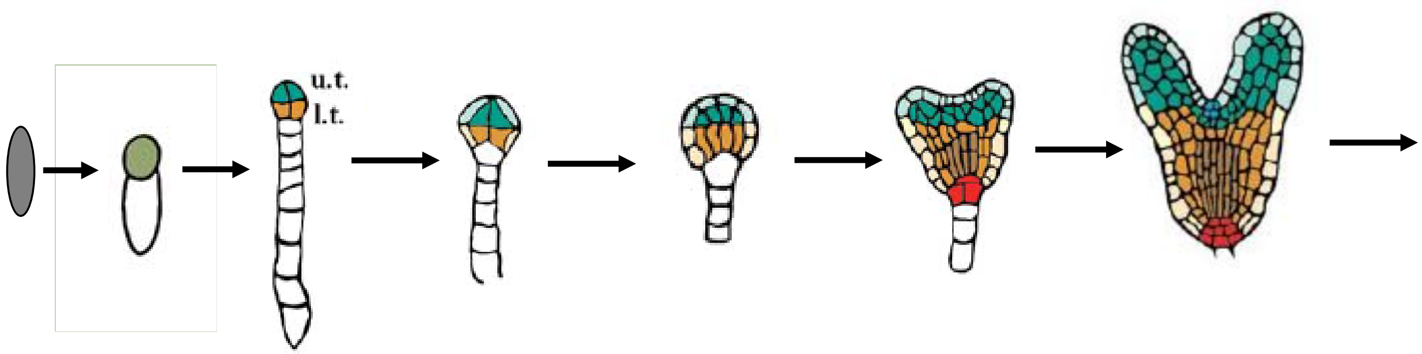
- Enlargement of cotyledons and hypocotyl.
- Vascular differentiation is visible.
- Suspenser cells undergo programmed cell death.



9. Mature embryo

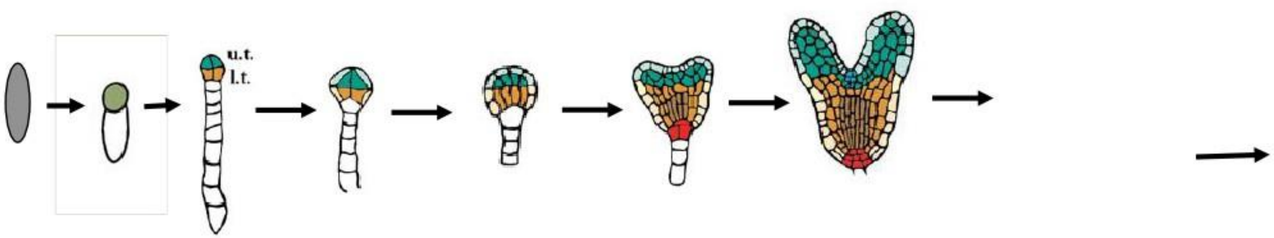
- Bent cotyledon (for some plant).
- Cell layers are clearly visible, specifying tissue and organ types.
- Embryo arrests and awaits desiccation and dormancy.





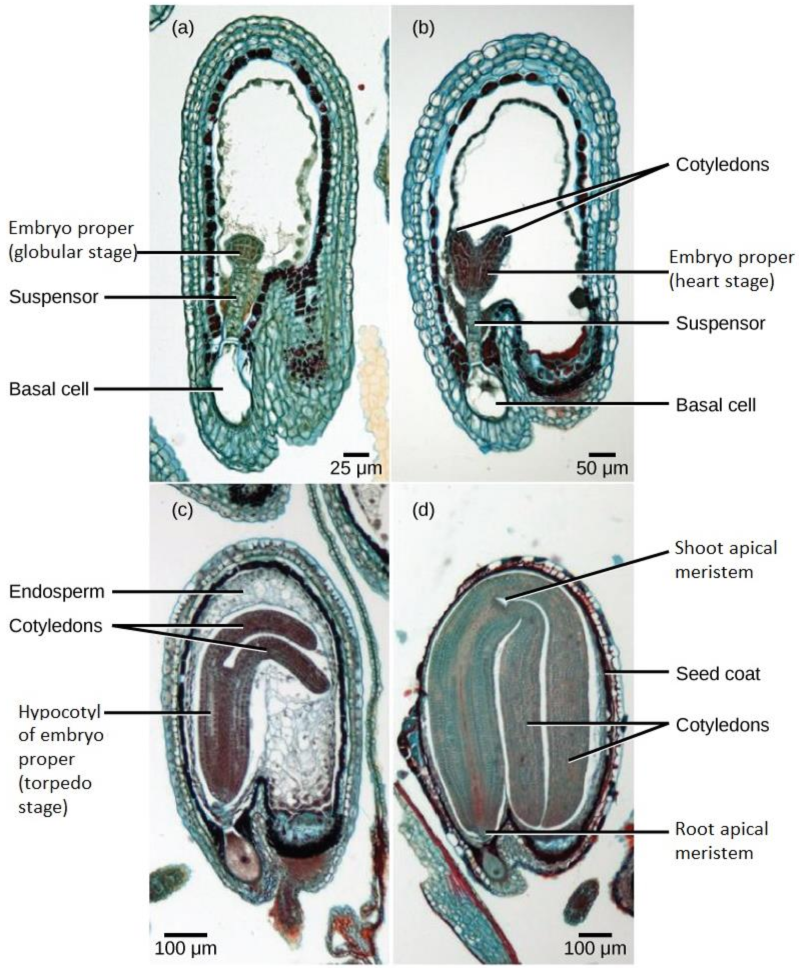
Embryo development

Embryonic origin of seedling structures: controlled by precise cell division, cell elongation and differentiation



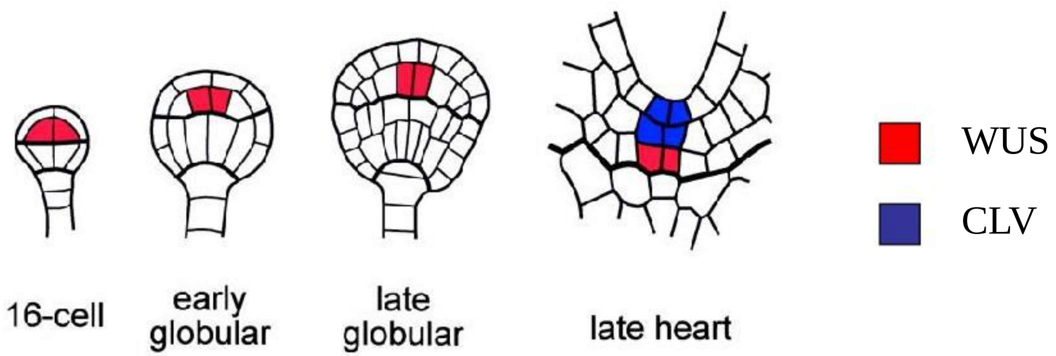
- Pattern establishment: apical/basal and radial axes
- Establishment of meristem regions

shoot apical meristem (SAM)
root apical meristem (RAM)

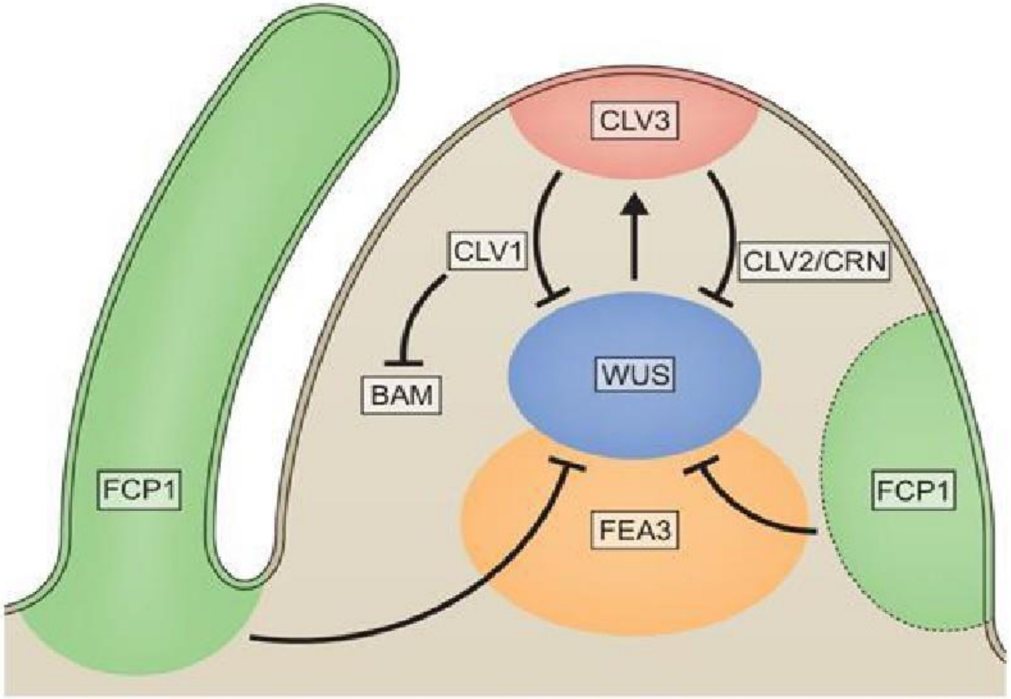

(a)
(b)
Embryo proper (globular stage)
Suspensor
Basal cell
25 µm
Cotyledons
Embryo proper (heart stage)
Suspensor
Basal cell
50 µm
(c)
(d)
Endosperm
Cotyledons
Hypocotyl of embryo proper (torpedo stage)
100 µm
Shoot apical meristem
Seed coat
Cotyledons
Root apical meristem
100 µm

Shoot apical meristem (SAM)

- Give rise to the shoot system of a plant
- Initiate in the apical domain of the dermatogen stage (16-cell) and well established at the heart stage.
- WUSCHEL (WUS) and CLAVATA play an essential role to maintain the integrity of SAM.

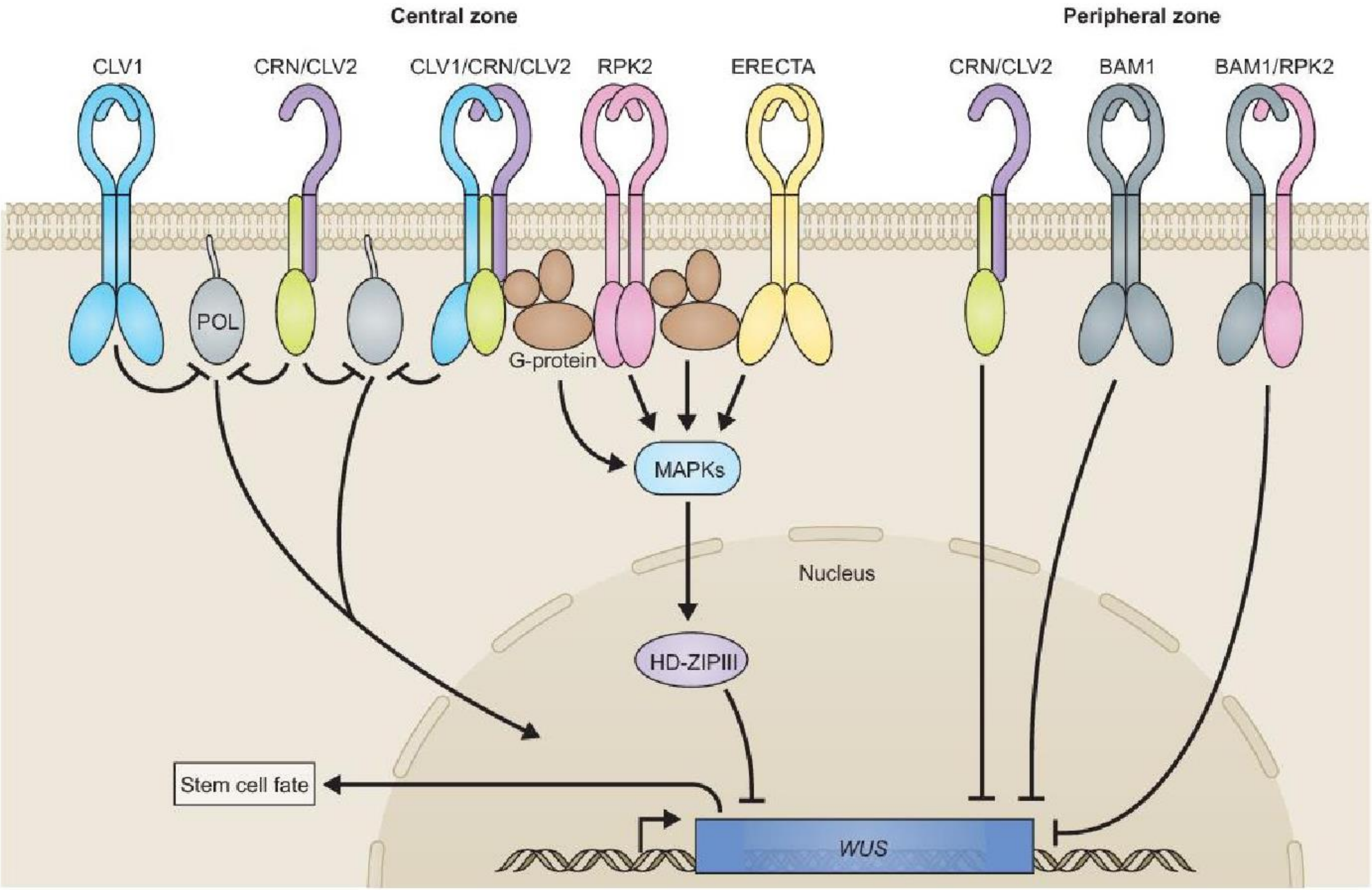


The CLAVATA (CLV)-WUSCHEL (WUS) signaling pathway has evolved as the central regulatory pathway that coordinates stem cell proliferation with differentiation. This coordination is achieved via an autoregulatory negative-feedback loop comprising the stem cell-promoting transcription factor WUS and the differentiation-promoting peptide CLV



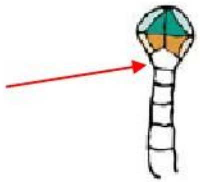
The WUSCHEL (WUS) protein plays a central role in the **maintenance of stem cell populations in shoot and floral meristems**. WUS positively regulates the size of each shoot meristem by maintaining the appropriate number of pluripotent stem cells in each shoot meristem.

CLAVATA1 (CLV1) is **a receptor protein expressed in the shoot apical meristem (SAM) that translates perception of a non-cell-autonomous CLAVATA3 (CLV3) peptide signal into altered stem cell fate**. CLV3 reduces expression of WUSCHEL (WUS) and FANTASTIC FOUR 2 (FAF2) in the SAM.


Central zone
Peripheral zone
CLV1
CRN/CLV2
CLV1/CRN/CLV2
RPK2
ERECTA
CRN/CLV2
BAM1
BAM1/RPK2
POL
G-protein
MAPKs
Nucleus
HD-ZIPIII
Stem cell fate
WUS

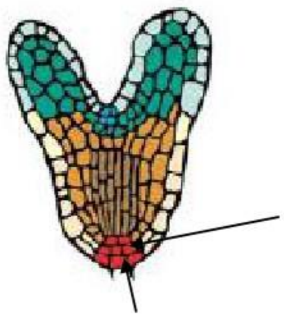
Root apical meristem (RAM)

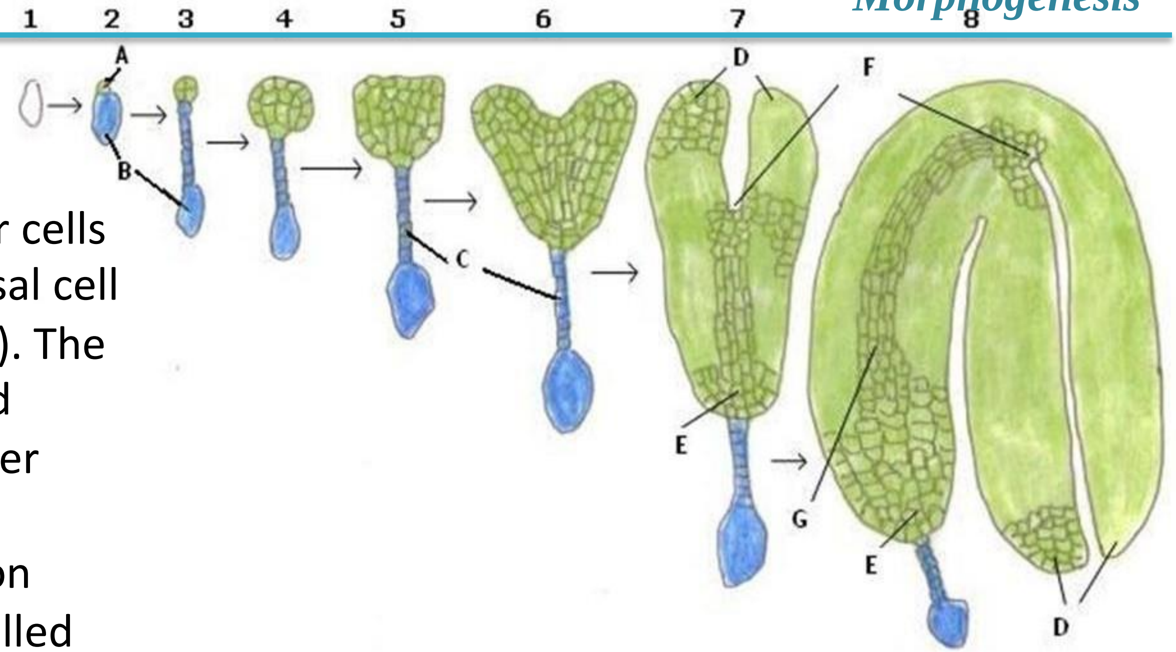
- Give rise to the root system of a plant
- Initiated from the suspensor as hypophysis at the dermatogen stage and established at the heart stage. Hypophysis develops into root apical meristem and the columella initials.



Dermatogen stage

Heart stage





a small apical cell (A) and a large basal cell B are formed

The apical cell divides into four cells and forms a small ball. The basal cell ligates cells at the top (stage 3). The apical clump of cells grows and forms a spherical ball. The lower part with the basal cell stops growing and dividing quite soon (stages 4 and 5). This part is called the suspensor

C) This stage (5) is called the globular stage of the embryo. The apical tissue grows sideward (stage 6), the cotyledons

D) are formed from this. At the same time the tissue between the cotyledons and the suspensor differentiates into the growing point of the root (or apical root meristem,

E), the growing point of the shoot (or apical shoot meristem,

F) and the connective vascular tissue

G) stages 7 and 8. The cotyledons grow and fold out.

Some facts about endosperm development

- Provide nutrients/signals for embryo development and seed germination.
- Developmental stages are not well understood/defined.

- Morphologically different in different species.

Hormones and embryogenesis and seed development

- Cytokinins: high during early embryo development, coinciding with the high rate of cell division.
- IAA: contribute to both cell division, enlargement, and differentiation during embryogenesis.
- GA: regulate cell enlargement during embryogenesis.
- ABA: appear at the late stages of embryo development (embryo maturation).

*stimulate accumulation of seed storage proteins.

*promote desiccation tolerance.

*Prevent precocious seed germination.

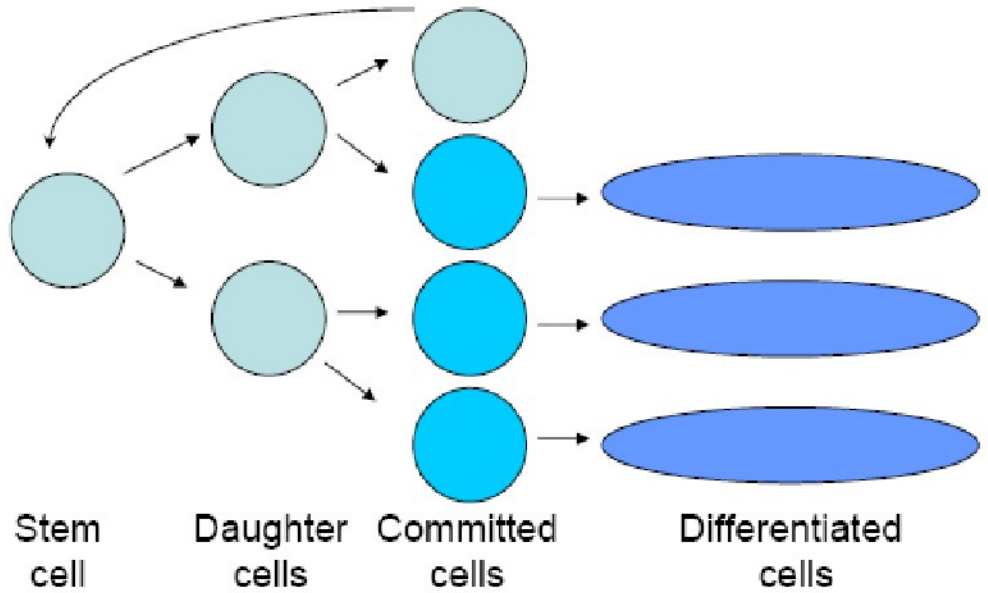
Meristems in plant development

What are meristems?

- Populations of small, isodiametric **cells** (having equal dimensions on all sides) **with embryonic characteristics**
- retain embryonic character indefinitely (**stem cells**), because some meristematic cells **do not undergo differentiation**

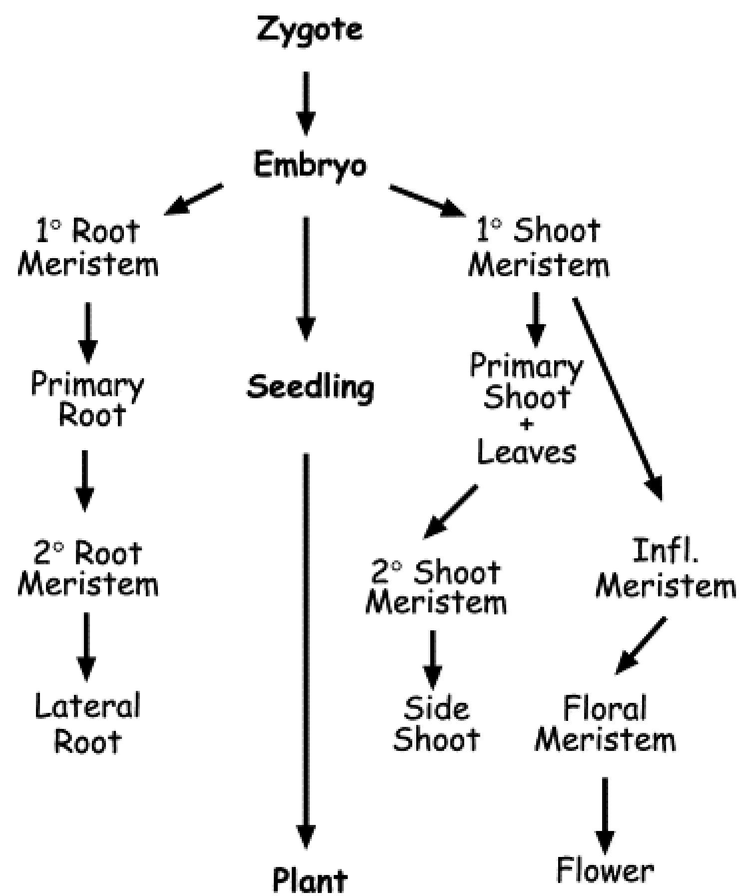
Vegetative meristems
- form body of root or stem
- continuously regenerate themselves

Reproductive meristem
- primary inflorescence meristem
- secondary inflor. meristem



Post-embryonic development refers to **the period of development after embryogenesis**.

During post-embryonic development, **the meristems produce new organs with reference to the existing body, transforming the juvenile seedling into the species-specific adult plant**.



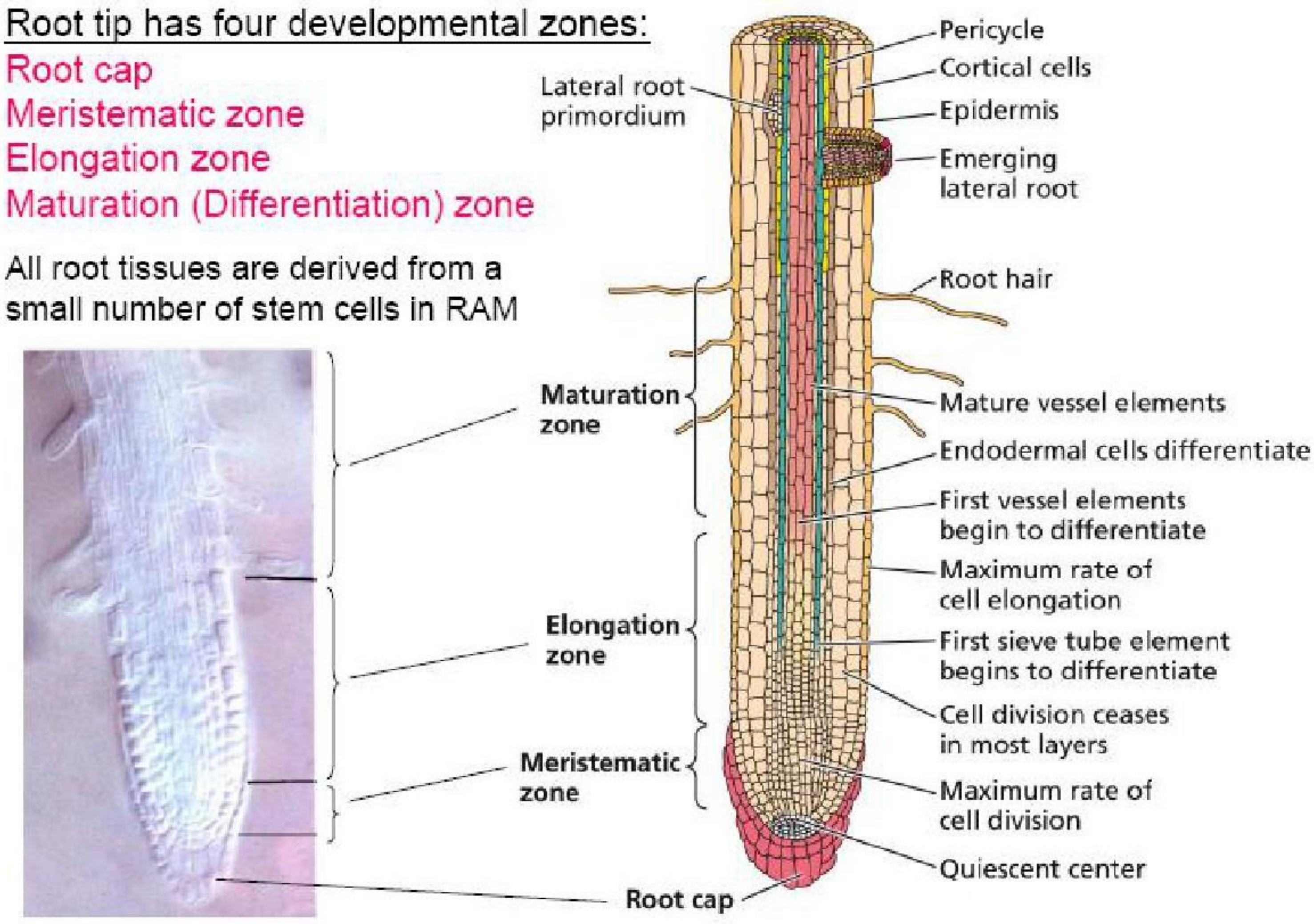
So, After embryogenesis, **plants pass through successive phases of vegetative and reproductive development**.

Root apical meristem (RAM)- Root development

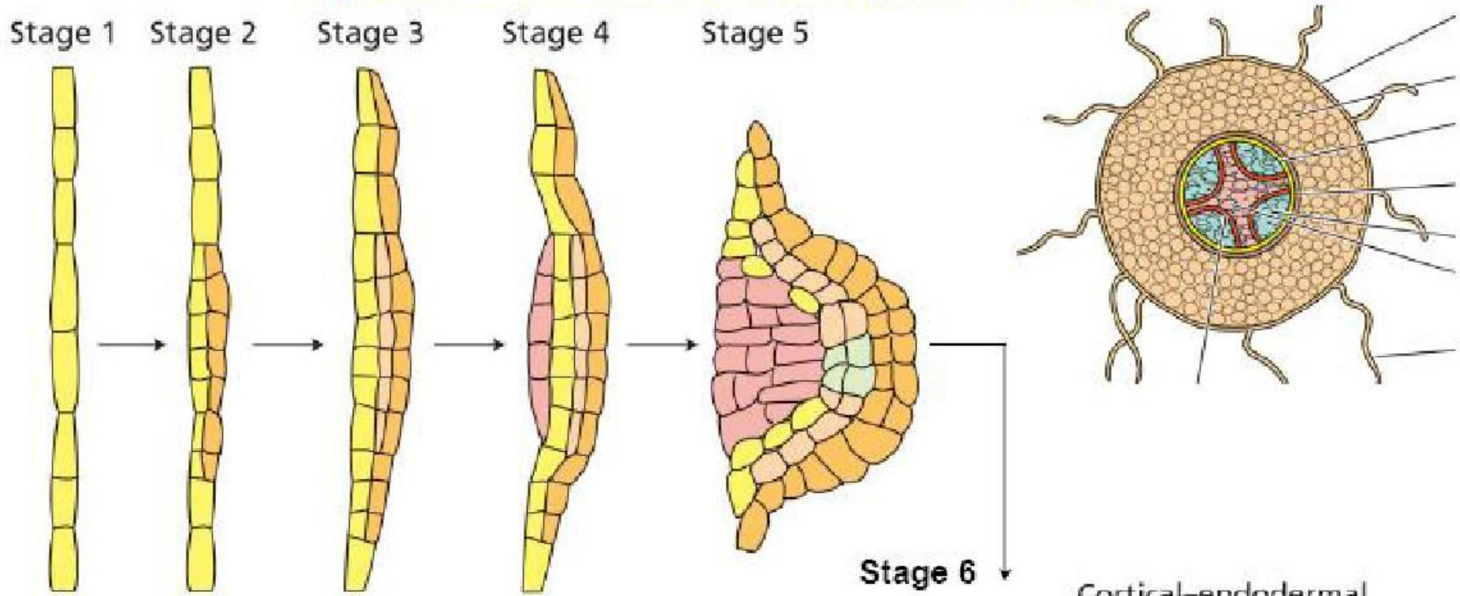
Root tip has four developmental zones:

Root cap
Meristematic zone
Elongation zone
Maturation (Differentiation) zone

All root tissues are derived from a small number of stem cells in RAM

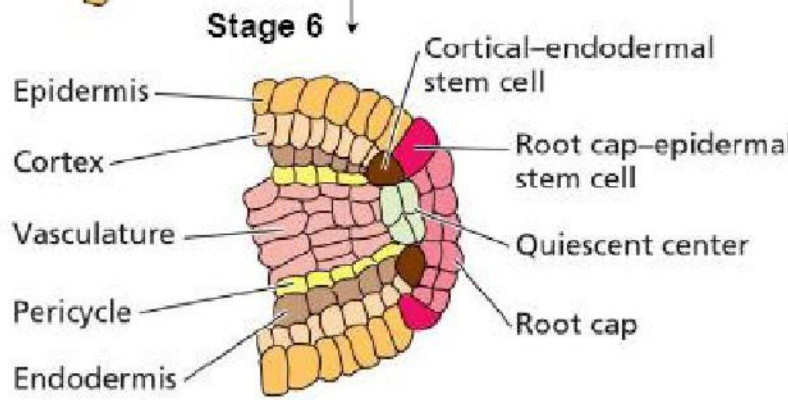


Model of lateral root formation

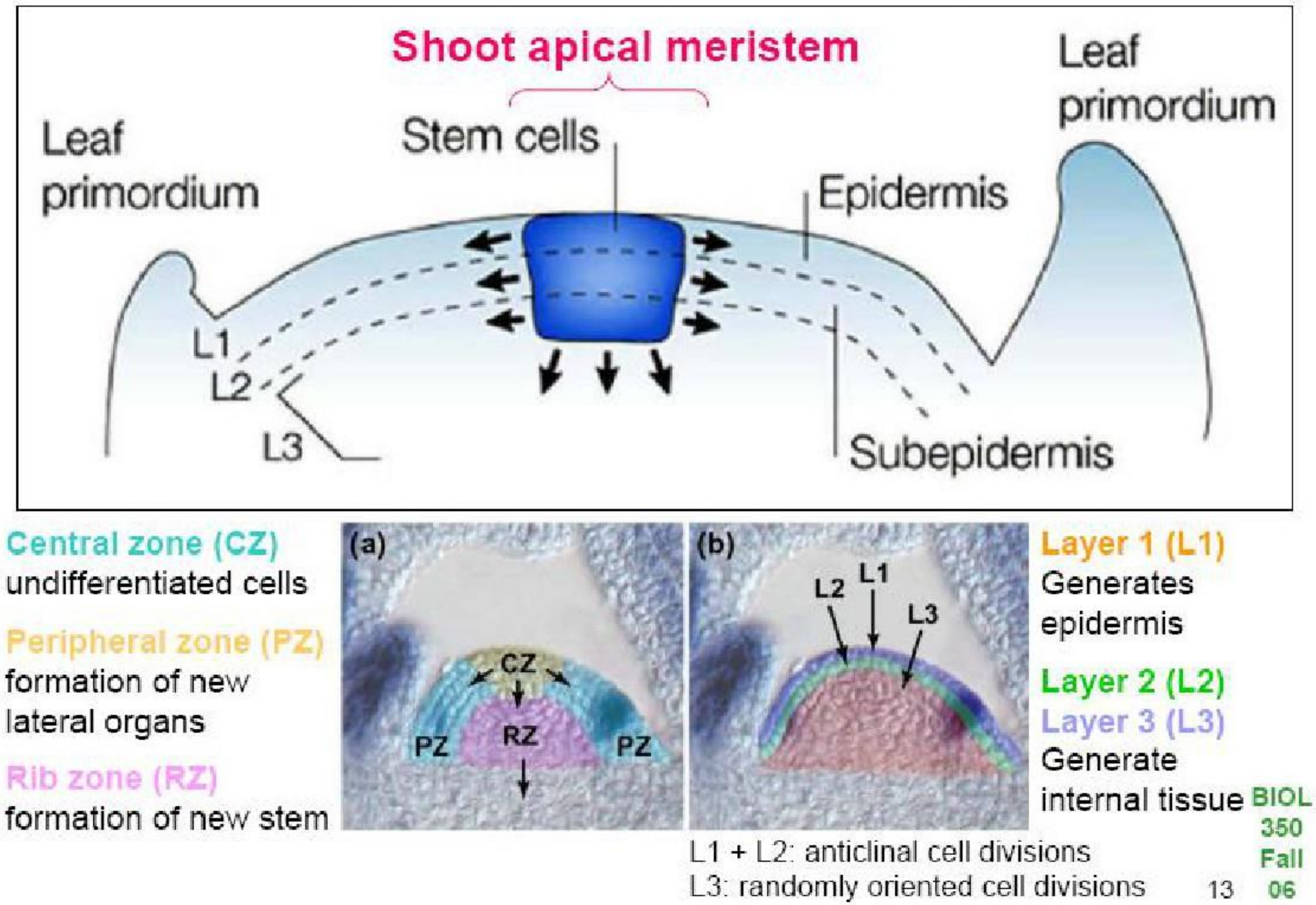


- Lateral roots arise form the **pericycle** in mature regions of the root

- Cell division in pericycle establish **secondary meristems** that grow out through the cortex and epidermis



Shoot apical meristem (SAM)



Alternative forms of embryogenesis.

A. Somatic embryogenesis. Somatic embryos are formed from plant cells that are not normally involved in the development of embryos, i.e. ordinary plant tissue. No endosperm or seed coat is formed around a somatic embryo.

B. Androgenesis. The process of androgenesis allows a mature plant embryo to form from a reduced, or immature, pollen grain. Androgenesis usually occurs under stressful conditions. Embryos that result from this mechanism can germinate into fully functional plants. As mentioned, the embryo results from a single pollen grain.

Six moments in embryogenesis

I. Two cell stage
II. Eight cell stage
III. Globular stage
IV. Heart stage
V. Torpedo stage
VI. Maturation

1. endosperm
2. single celled zygote
3. embryo
4. suspensor
5. cotyledons
6. shoot apical meristem (SAM)
7. root apical meristem (RAM)