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10 PLANT GROWTH AND DEVELOPMENT

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PLANT GROWTH AND DEVELOPMENT

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1 PLANT GROWTH AND DEVELOPMENT

GROWTH, TYPES OF GROWTH, GROWTH CURVE, GROWTH RATES

Key Takeaways

- Growth
  - Germination
  - Types of growth
  - Phases of growth
  - Sigmoid growth curve
  - Measurement of growth
  - Growth rate

Prerequisites

Meristem
Specific areas in plants that take part in the formation of new cells

- **Apical meristem**
  - **Root apical meristem**
  - **Shoot apical meristem**
- **Intercalary meristem**
- **Lateral meristem**

Growth

- It is an irreversible permanent increase in the size of an organ or its part or even of an individual cell.
- It is the property of living beings but not a defining property.

Germination

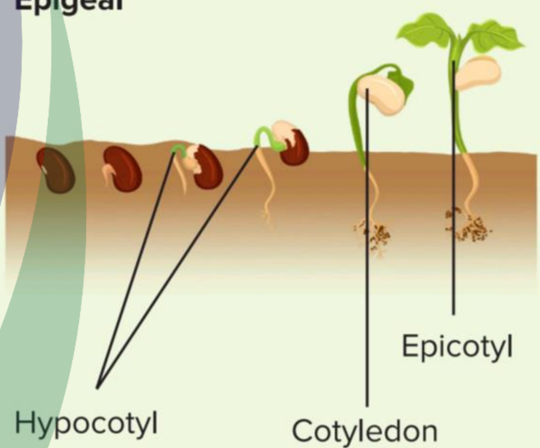
- The process of emergence and growth of a plant's embryo present in the seed is known as **germination**.
- The embryonic leaf is known as **cotyledon**.
- The region between the cotyledonary node and plumule is known as the **epicotyl**.
- The region of the embryonic axis that bears cotyledons and lies below the cotyledon is known as the **hypocotyl**.

Classification of Germination

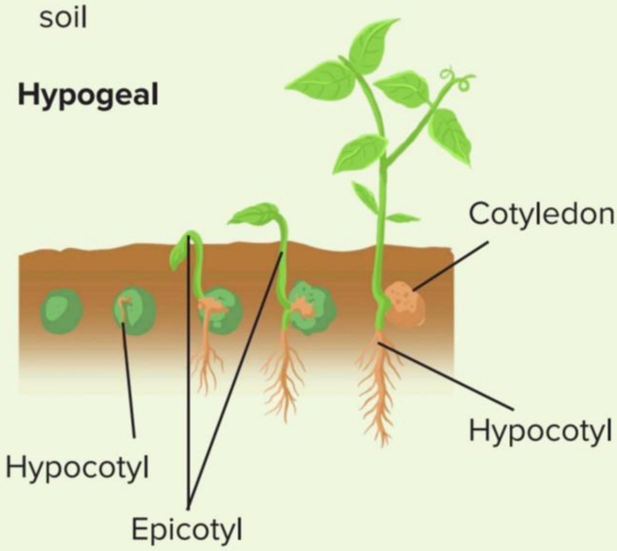
Germination
(Based on the emergence of cotyledon from the seed)

Epigeal	Hypogeal
The hypocotyl and epicotyl emerge out of the soil.	Only the epicotyl emerges out of the soil and the hypocotyl remains in the soil

Epigeal



Hypogeal



Note

Irrespective of the type of germination, the growth of tip (shoot and root) continues as the plant grows.

Did you know?

A Special Type of Germination

Viviparous Germination

- In this type of germination, the seeds germinate while they are **attached to the parent body.**
- These seeds cannot germinate in **high saline water.**
- This is mostly seen in the **mangrove plants.**

Viviparous germination in mangrove

Types of growth

Growth (Based on the meristematic activity)
- **Indeterminate growth**
- **Determinate growth**

Indeterminate growth

- Growth **continues** till the plant lives.
- The plant grows from seed to tree due to shoot apical meristem and root apical meristem.
- Meristem involved in this growth is known as **intermediate meristem**.
- Also known as **intermediate growth**

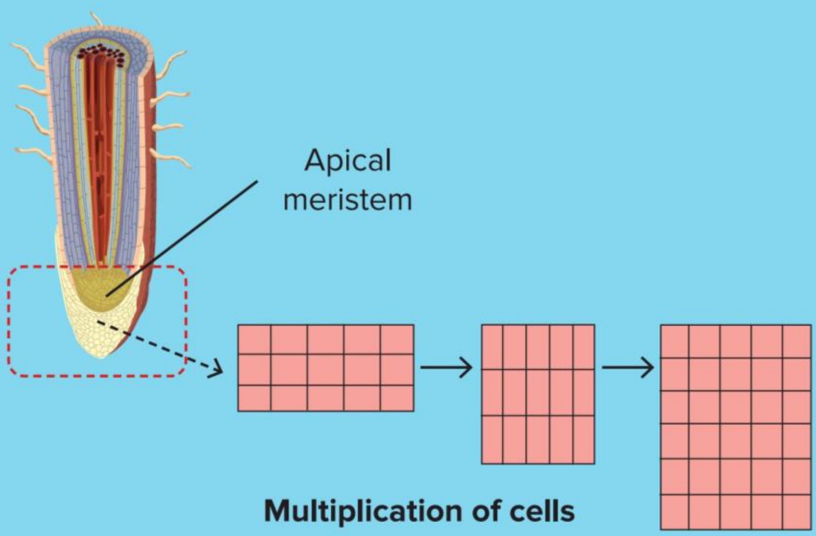
Determinate growth

- Growth **does not continue** throughout the life of plant.
- It is often seen in the fruits and leaves.
- **Intercalary meristem** is involved in the formation of fruits/organs.
- **Growth stops at a point** as seen in the animals.

Phases of growth

Formative phase

- Predominantly **at the tip of the root** and **shoot**, there are a lot of meristematic cells.
- This phase is responsible for the **growth** of the roots and shoot tips of the plants.
- This phase is responsible for **production of new cells** by the mitosis of meristematic cells.
  - The **rate of respiration** is **high** in these cells.
  - The meristematic cells have a **dense cytoplasm**.
  - Meristematic cells also have a **thin cell wall** that aids in cell division.
    - **Example**: Apical meristem of maize adds 17,500 new cells per hour

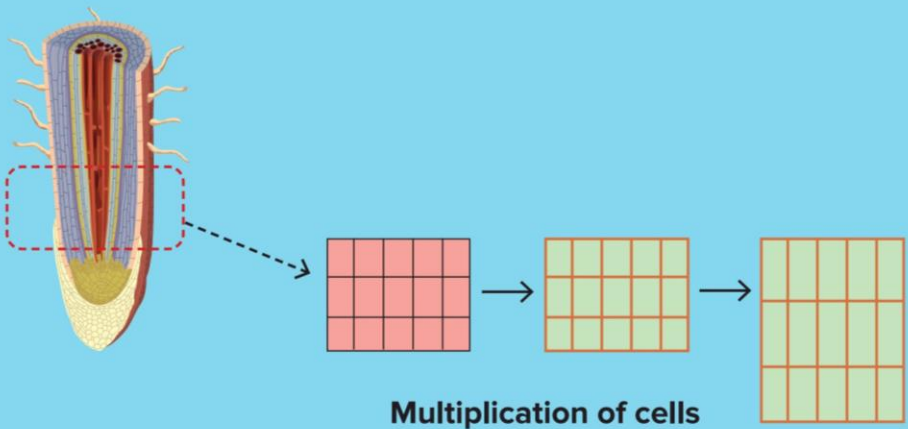


Multiplication of cells

Enlargement phase

- This occurs in the new cells formed in the **formative phase**.
- In this phase, the cells are not capable of dividing.
- The new cells **enlarge** and **elongate**.
- **Vacuolation** is the process of the development of vacuoles, and helps in the enlargement of cell size.

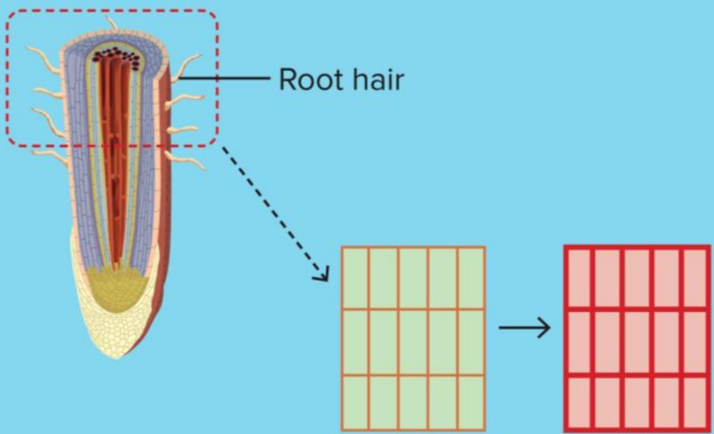
- **Secondary cell wall depositions** are observed.
- The rate of respiration is **lower** than the cells in the formative phase.
  - **Example**: Watermelon cells can enlarge up to 3,50,000 times.



Multiplication of cells

Maturation phase

- The cells completely **lose the ability to divide** in this phase. No new cells are formed.
- Structural and physiological differentiation occurs.
- They **gain permanent functions.**
  - The cells constituting this phase forms the **region of differentiation.**
- The cell wall becomes thick along with some protoplasmic modifications.
- In **parenchymatous cells**, the protoplasm is alive and functional.
- In **cork cells**, cutin and suberin are deposited.
- Loss of the nucleus along with other organelles occur in **sieve tube cells.**



Multiplication of cells

Measurement of growth

Surface area

- An increase in the surface area helps to measure the growth in flat organs like leaves.
- The leaf is placed on a graph and its outline is traced.
- Based on the outline, the surface area covered by the leaf is measured.
- Hence, the growth is measured based on the increase in surface area.

Volume

- An increase in volume is used to measure the growth of fruits.
- The fruit is dipped in water.
- The difference in the volume of water before and after the fruit was added indicates the volume of the fruit

Weight

- An increase in the weight of the plants is used to measure the growth.

- It is represented as follows:
  - **Dry weight:** The plant material is dried in an oven at 110 degree Celsius for a few hours or air dried for a few days to remove the water content.
    - It is the weight of the plant material after the removal of the water content.
  - **Fresh weight:** It is the weight of the living tissue along with the water content.

Fresh leaves **Dry leaves**

Girth

- An increase in the diameter of the tree is a parameter for growth in terms of girth.
  - **Example:** Globular and cylindrical plant organs like fruits, tree trunk
- It can be measured by a **tape or Vernier calipers**.

Measurement of girth

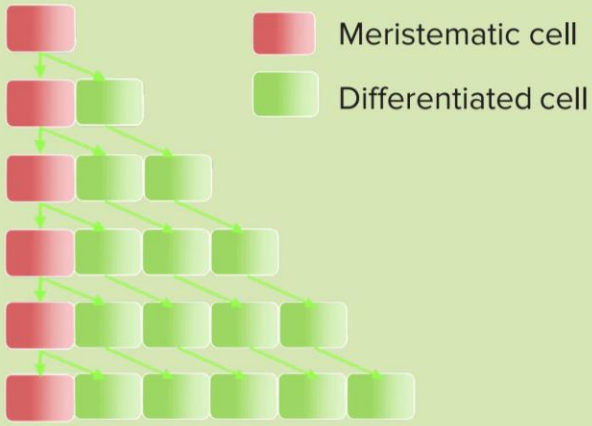
Number of cells

- The rate of growth is directly proportional to the increase in the number of cells.
  - **Example**: Algae, plant cells growing in a culture

Types of growth (Based on number of cells)

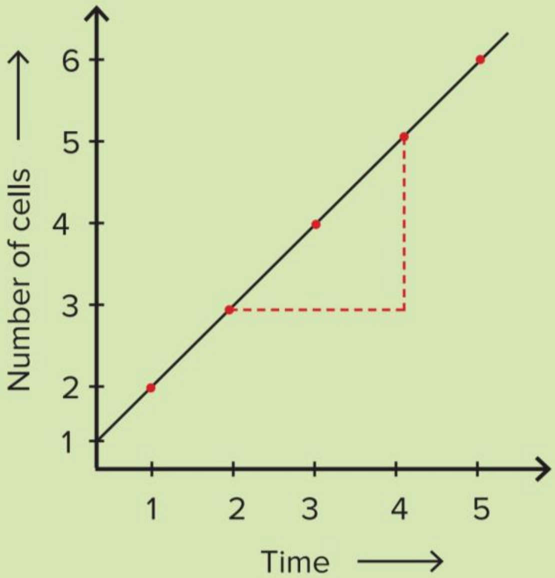
Arithmetic growth

- As the plant grows, in every generation, new daughter cells are produced
  - One daughter cell retains meristematic activity.
  - The others start to differentiate, i.e., undergo maturation.
- The retained meristematic cell undergoes further cell division.
- The growth pattern repeats.



Graphical description

- Plot the number of cells against time.
- Mathematical expression
  - $L = rt + L_0$
  - $y = mx + c$
  - $G_t = rt + G_0$
- G_t = Growth at time t
- G_0 = Growth at time zero
- r = Growth rate = $\frac{\text{Change in parameter}}{\text{Change in time}}$
- The rate of growth is constant.
- **Growth is in arithmetic progression.**



Geometric growth

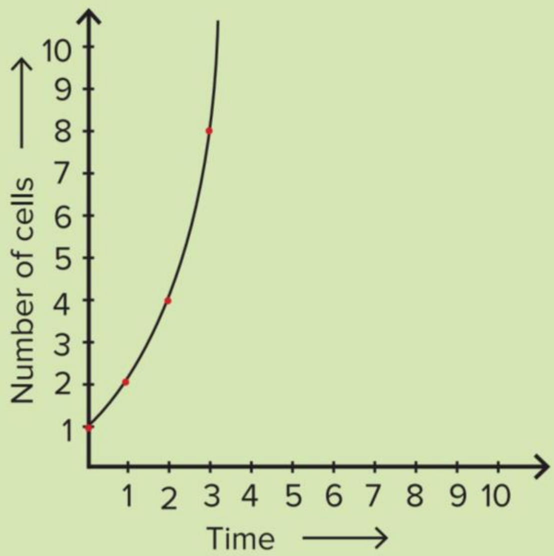
- As the plant grows, in every generation, new daughter cells are produced
  - All the daughter cells retain meristematic ability.

- They do not mature.
  - All the cells can divide.
- The rate of growth varies in different species and organs.
- Examples: i) The growth of cacti is extremely slow.
  ii) Young leaves of banana grow rapidly (3 inches per hour).

- Growth begins slowly. The graph enters a period of rapid enlargement, i.e., hike in growth is observed.
- It is followed by a decrease in graph till no further enlargement (the cells start to die and no new growth is seen).

Graphical representation

- Mathematical expression
  - $W_1 = W_0e^{rt}$
  - W_1 = Size at time t (Weight, height, number, and more)
  - W_0 = Initial size
  - r = Growth rate
  - t = Time of growth under consideration
  - e = Base of natural logarithms
- **Example**: $W_0 = 1$

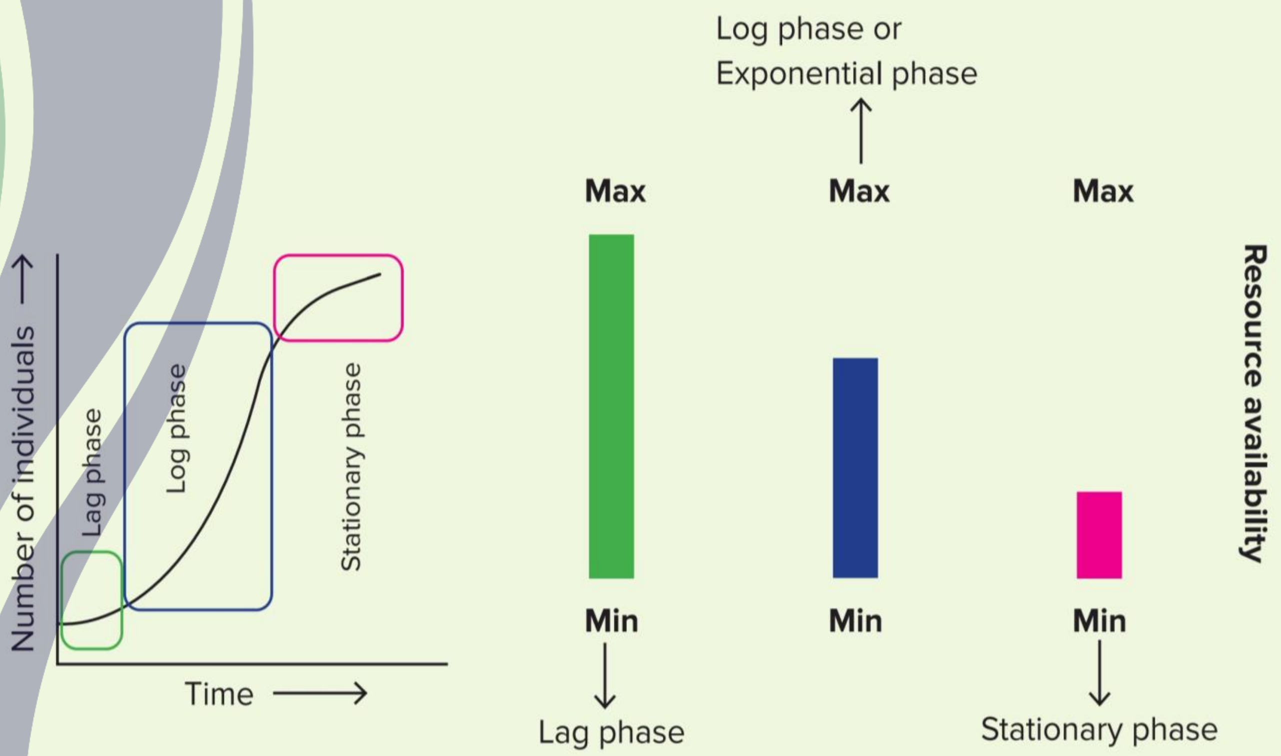


Note

This exponential growth cannot continue forever. Thus, as mentioned the growth gradually starts to decrease. After some point, the nutrients required for the growth starts to deplete. This leads to slower growth.

Sigmoid growth curve

- It is an **S-shaped** growth curve.
- It includes **three** phases.
  - **Lag phase**
  - **Exponential phase**
  - **Stationary phase**



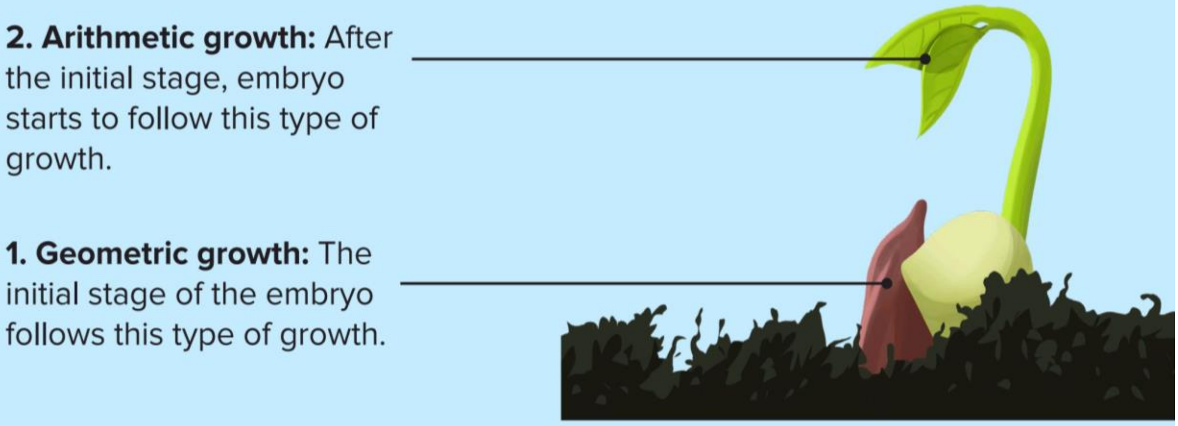
- **Lag phase**
  - The **growth** is **very slow.**
  - Cells have a lot of resources, i.e., a lot of nutrients are available.
  - Since few cells are only present at an initial stage and they take time to get accustomed to the surrounding as well as the nutrients, the growth is slow.
- **Log phase or exponential phase**
  - Gradually, the cells start to **grow faster.**
  - More numbers of cells are observed.
  - The exponential growth of cells is observed as nutrients are also available for all the cells.
  - In this phase, the resources and the number of cells present are high.
  - **End of log phase:** The cells start to grow exponentially. As they grow, they deplete the available resources.
  - This indicates the end of the log phase.
- **Stationary phase**
  - The stationary phase starts where the log phase ends.
  - The speed of the growth of the cells gradually slows down.
  - A **saturation** in growth is observed due to limited resources.
  - The **cells stop dividing** as they reach towards saturation.

Note

The arithmetic growth and stationary growth may not occur individually.
Both the types of growths are combined and highly orchestrated to aid in plant growth.

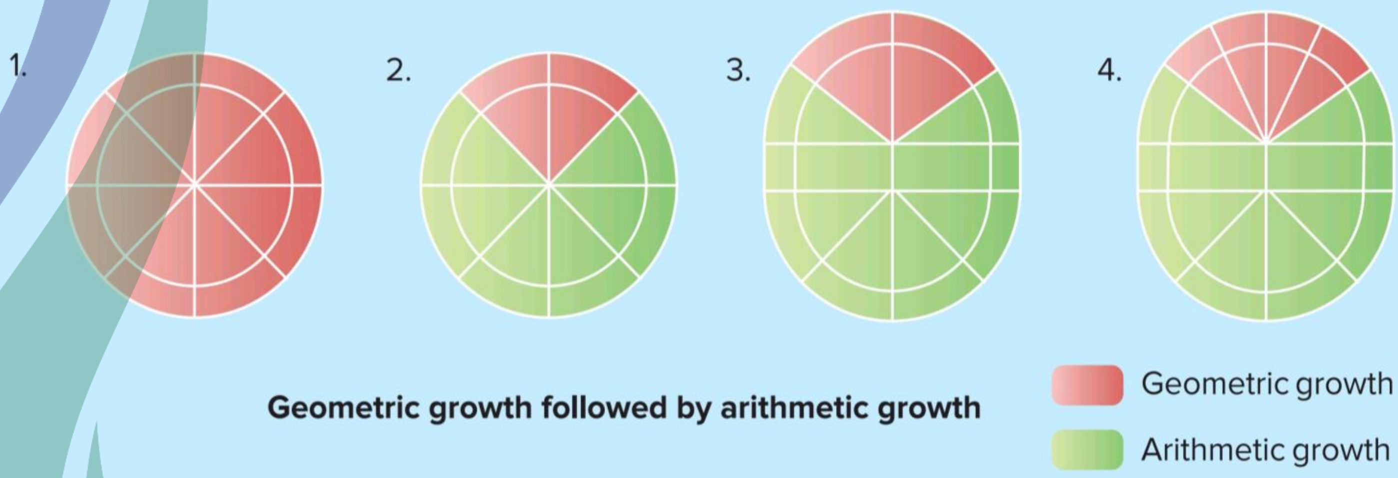
Geometric Growth and Arithmetic Growth

- They occur in embryos.



Growing plant embryo in the seed

- Geometric growth is followed by arithmetic growth.
- Meristematic cells are involved in geometric growth.
- Once a few cells are formed, some cells lose their ability to divide. At this point, the embryo switches to arithmetic growth.
- The cells start to **differentiate** in arithmetic growth.



Geometric growth followed by arithmetic growth

Growth rate

- It is a measure of how much growth has taken place in a given time.

Absolute growth rate

- Growth per unit time

$$AGR = \frac{\text{Final perimeter - Initial perimeter}}{\text{Time}}$$

Relative growth rate

- Growth per unit time per initial parameter

$$RGR = \frac{\text{Final perimeter - Initial perimeter}}{\text{Time} \times \text{Initial perimeter}}$$

Experiment time

- The initial area of the leaf is measured.
- After a certain period, the surface of the same leaf is measured again.
- Both the leaves have grown.

Calculations

AGR

	Initial area	Final area		Initial area	Final area
A	5 cm²	10 cm²	**B**	50 cm²	55 cm²

- $$AGR = \frac{\text{Final perimeter - Initial perimeter}}{\text{Time}}$$

AGR for leaf A = $\frac{10 - 5}{t} = \frac{5\ cm^2}{t}$

AGR for leaf B = $\frac{55 - 50}{t} = \frac{5\ cm^2}{t}$

RGR

	Initial area	Final area		Initial area	Final area
A	5 cm^2	10 cm^2	**B**	50 cm^2	55 cm^2

- $$\textbf{RGR} = \frac{\textbf{Final perimeter - Initial perimeter}}{\textbf{Time} \times \textbf{Initial parameter}}$$

$$\text{RGR for leaf A} = \frac{10 - 5}{t \times 5} = \frac{5}{5 \times t} = \frac{1\ cm^2}{t}$$

$$\text{RGR for leaf B} = \frac{55 - 50}{t \times 50} = \frac{5}{50 \times t} = \frac{0.1\ cm^2}{t}$$

Summary sheet

Germination

- **Epigeal**: The hypocotyl and epicotyl emerge out of the soil
- **Hypogeal**: Only the epicotyl emerges out of the soil and the hypocotyl remains in the soil

Growth

Indeterminate growth

- Growth seen throughout the lifespan of plants
- Shoot apical meristem and root apical meristem help the plant grow from seed to tree

Determinate growth

- Growth does not continue through out the lifespan
- Growth seen in leaves and fruits

Phases of growth

Formative phase

This phase is responsible for the growth of the roots and shoot tips of the plants.

Enlargement phase

This cells are not capable of dividing. The new cells enlarge and elongate.

Maturation phase

The cells completely lose the ability to divide. No new cells are formed. Structural and physiological differentiation occurs.

Parameters of growth

Surface area

Number of cells

Girth

Volume

Fresh leaves **Dry leaves**

Weight

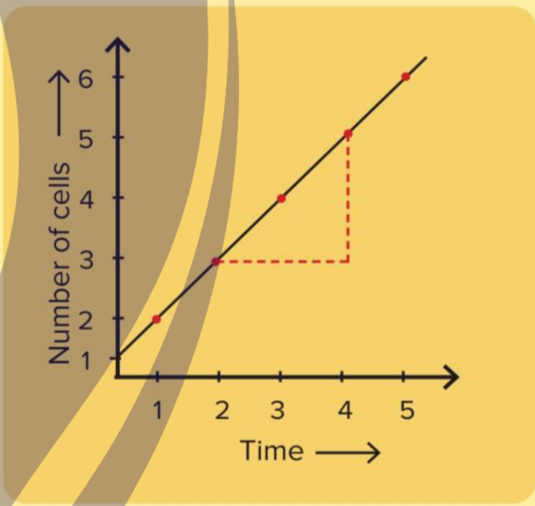
Growth

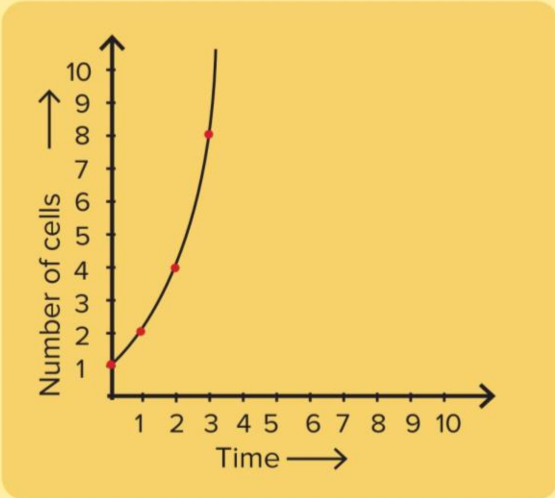
Arithmetic growth

As plant grows, new cells are produced. The number of cells produced increases with respect to the constant time interval

Geometric growth

As plant grows, new cells are produced. The number of cells produced increases with square of time.





Formula 1

$G_t = rt + G_0$

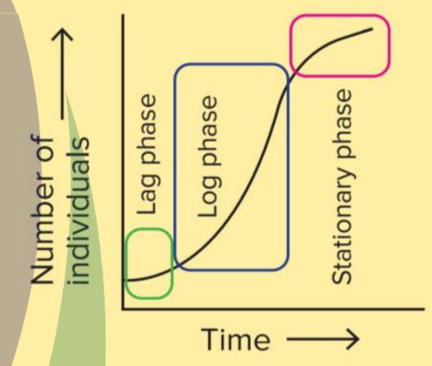
- G_t = Growth at time t
- G_0 = Growth at time zero
- r = Growth rate = $\frac{\text{Change in parameter}}{\text{Change in time}}$

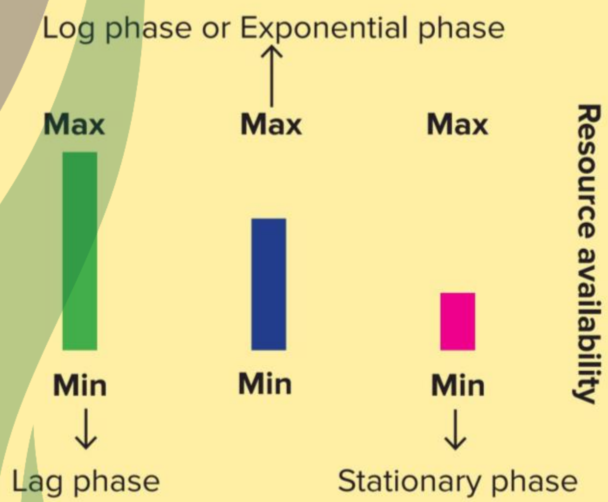
Formula 2

$W_1 = W_0 e^{rt}$

- W_1 = Size at time t (Weight, height, number, and more)
- W_0 = Initial size
- r = Growth rate
- t = Time of growth under consideration
- e = Base of natural logarithms

Sigmoid growth curve





Growth rate

Absolute growth rate

$$AGR = \frac{\text{Final perimeter - Initial perimeter}}{\text{Time}}$$

Relative growth rate

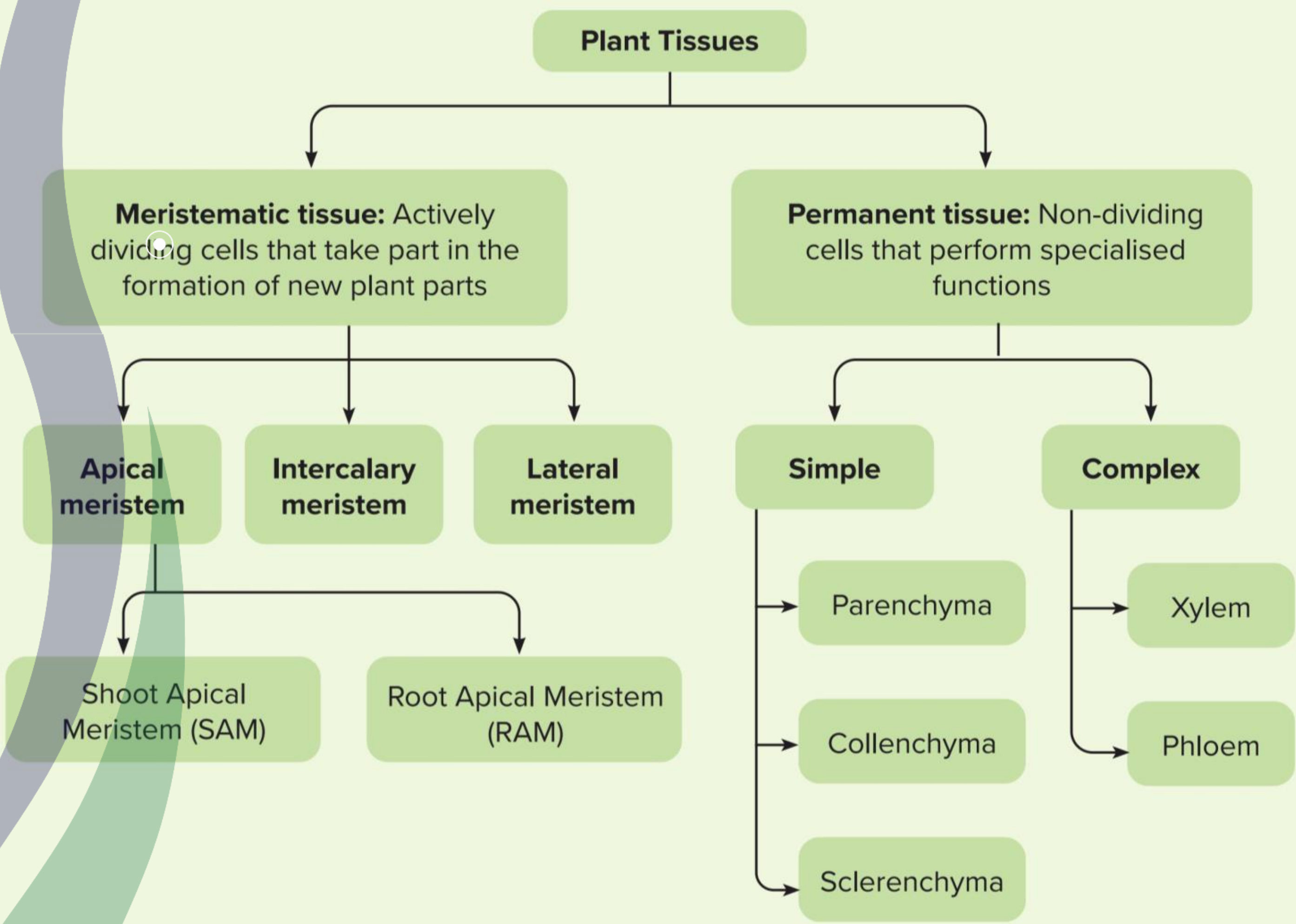
$$RGR = \frac{\text{Final perimeter - Initial perimeter}}{\text{Time} \times \text{Initial perimeter}}$$

DIFFERENTIATION, DEDIFFERENTLATION AND REDIFFERENTIATION, PLANT DEVELOPMENT, TYPES OF PLANT GROWTH REGULATORS

Key Takeaways

- Differentiation
- Dedifferentiation
- Redifferentiation
- Plant development
- Phytohormones

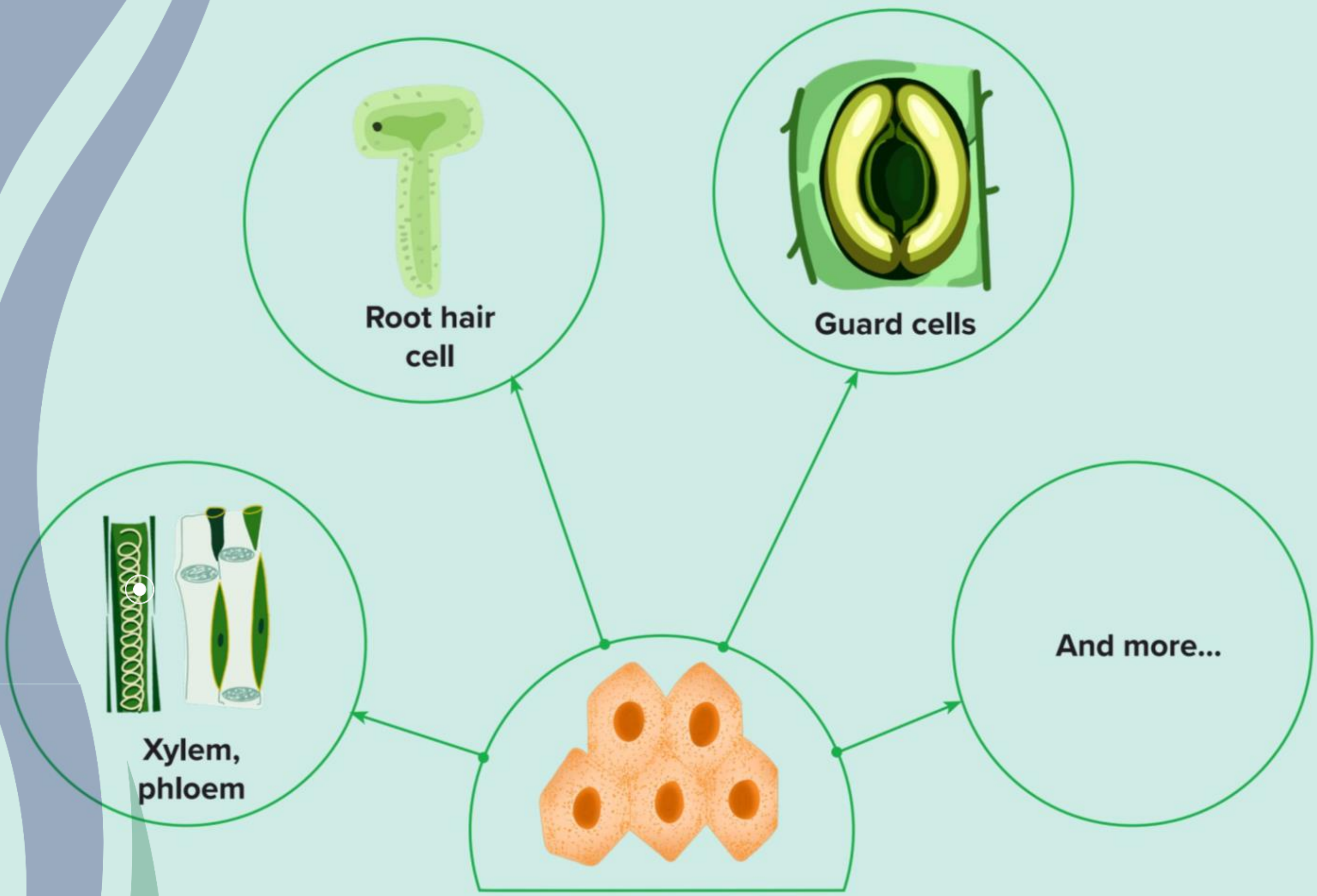
Prerequisites



- **Indeterminate growth in plants**
  - The growth of the plant throughout its lifespan from seed to tree is known as indeterminate growth.
  - This type of **unlimited growth** is due to **meristems**.

Meristems

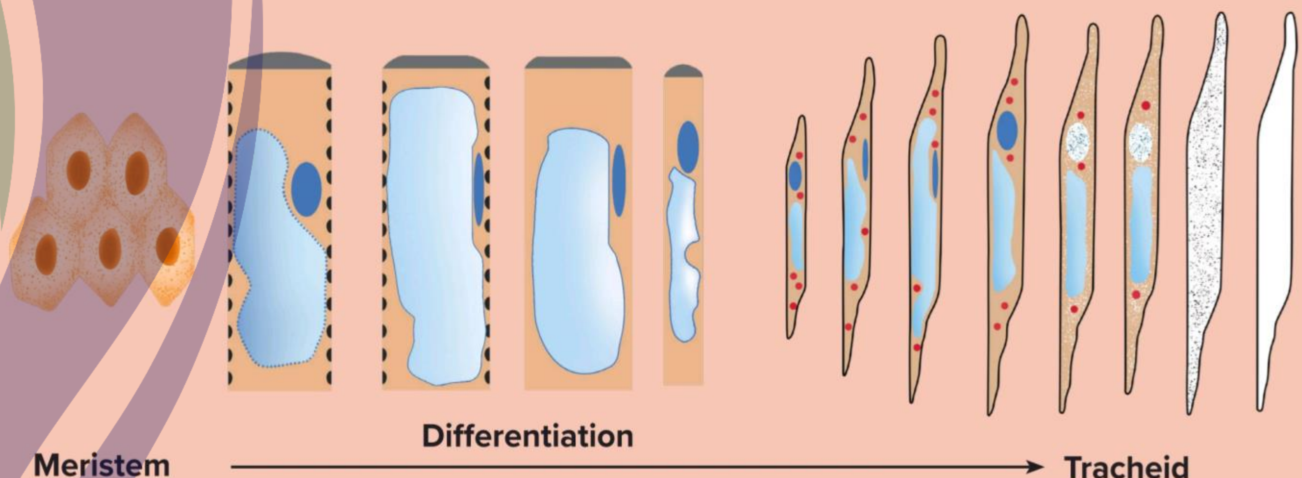
- Meristems are **undifferentiated totipotent cells**.
  - » **Totipotent**: Capable of giving rise to any type of specialised cell
  - » **Undifferentiated**: Cells that have not yet developed into a specialised cell type
- Specialised cells are essential for performing specialised functions.
- Meristems develop into specialised cells through the process of **differentiation**.



Various types of specialized cells arising from meristem

Differentiation

- **Differentiation** refers to the **structural** and **functional** changes that a meristematic cell undergoes to perform a specific function and thereby, loses the ability to divide.
  - » **Meristems** differentiate to form **permanent tissues** (simple and complex).
  - » Example: **Differentiation of meristematic cell** to form **tracheary element.**

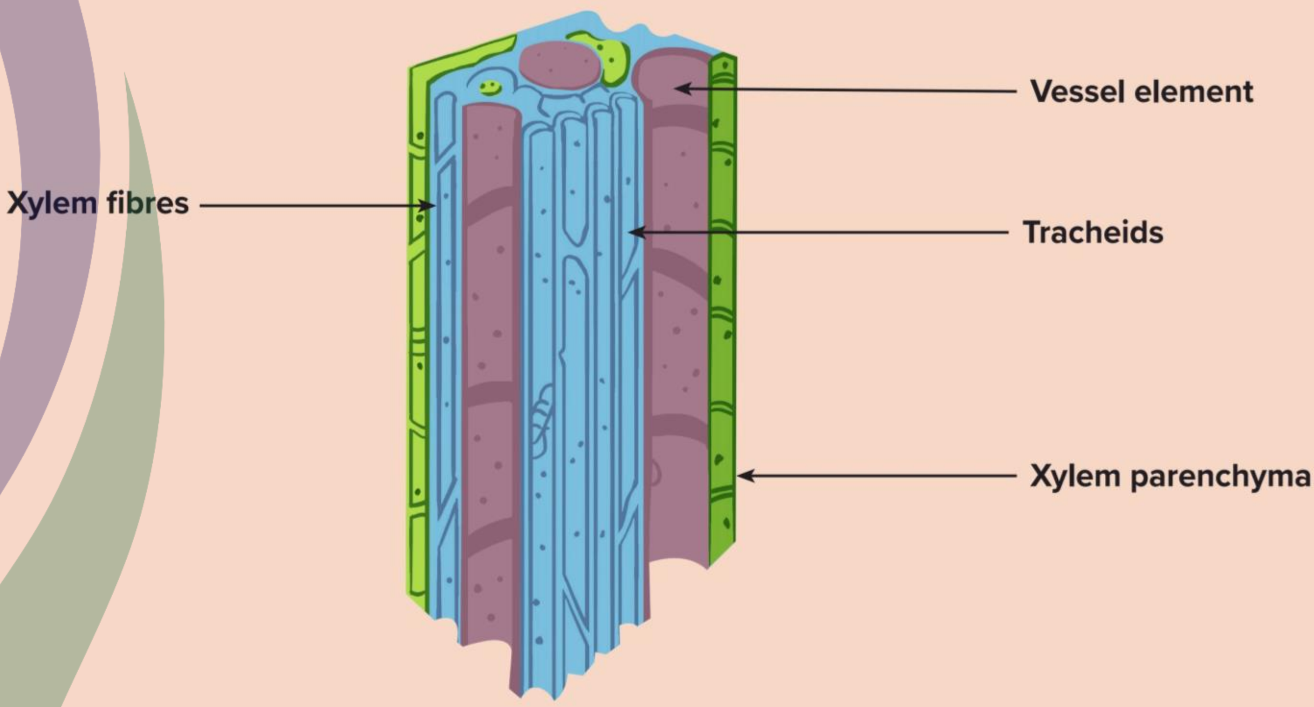


Structural change: Meristem elongates + Loses protoplasm + Develops very strong, elastic, lignocellulosic secondary cell walls

Function: Long-distance water transport under extreme tension

Tracheary elements

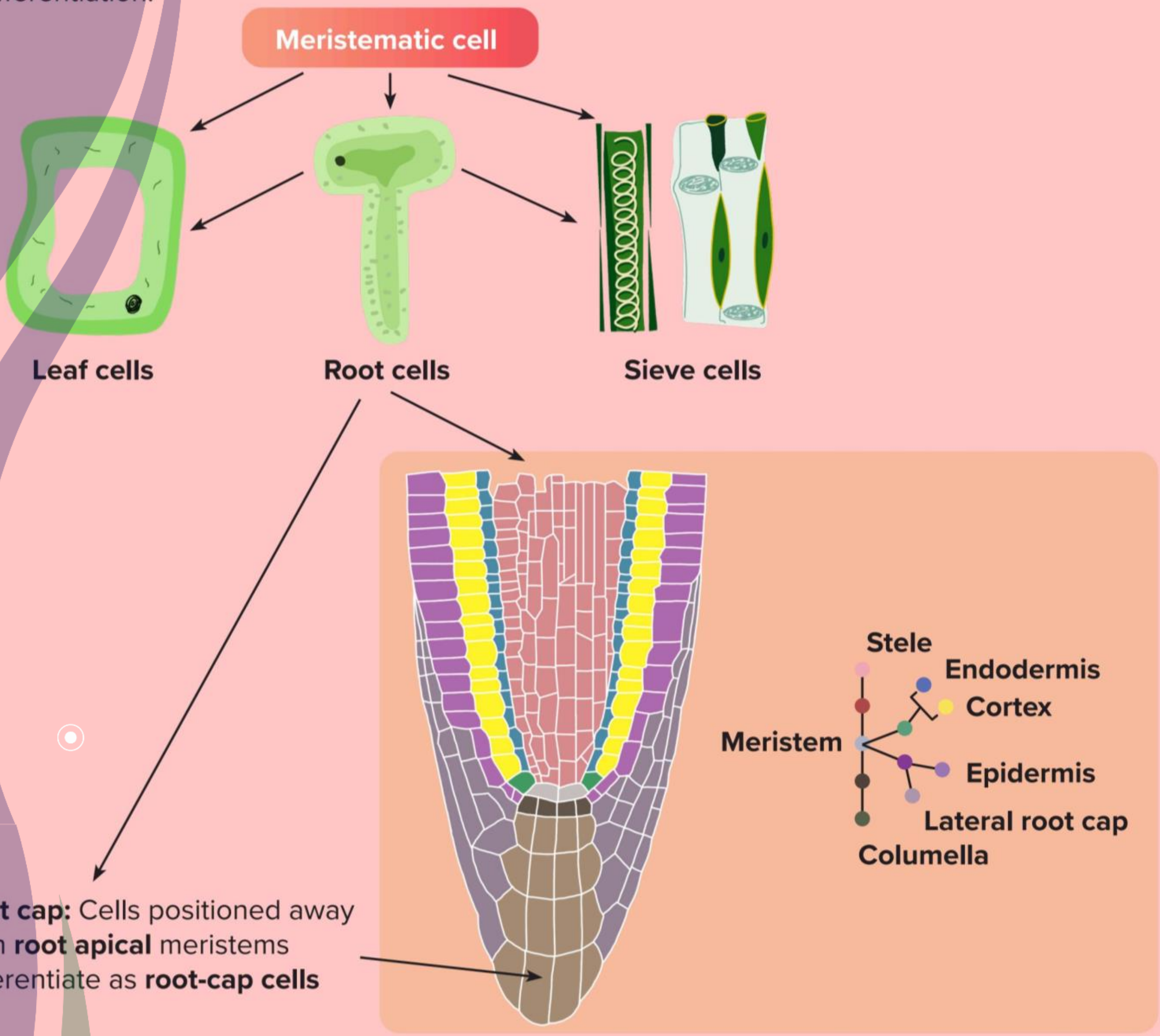
- Includes **xylem vessels** and **tracheids**
  - Dead, hollow cells with patterned cell walls
  - They are alive during the developmental stage and dead when fully differentiated
  - Help in conduction of water and mineral salts



Components of xylem

Did you know?

- **Differentiation is open:** Cells arising from the same meristem have different structures after differentiation.

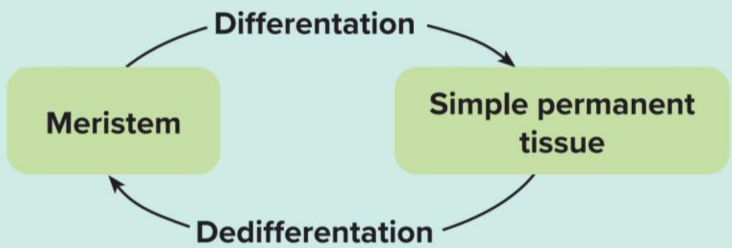


Root cap: Cells positioned away from **root apical** meristems differentiate as **root-cap cells**

Dedifferentiation

- The living **differentiated cells regain the ability to divide** and lose the ability to perform specific functions.

Meristem develops into a specialised cell to perform a particular function and loses ability to divide.



Living differentiated cells regain the ability to divide.

Dedifferentiation and Secondary growth

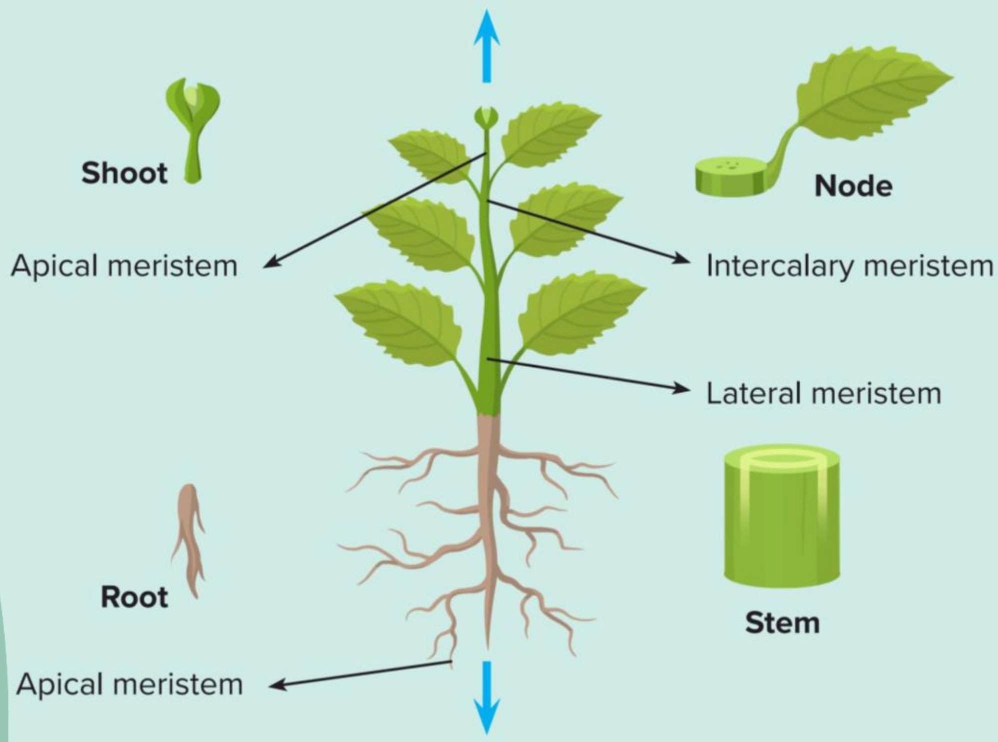
Meristem

Primary meristem

- Responsible for **primary growth**
- Plant grows in **length**
- **RAM** and **SAM** are types of primary meristem

Secondary/Lateral meristem

- Responsible for **secondary growth**
- Plant grows in **girth** (diameter)
- Secondary meristem formed by dedifferentiation of permanent cells (like parenchyma)
- **Vascular** and **cork cambium** are types of secondary meristem



Cambium

Vascular cambium

- Responsible for increasing the diameter of stems and roots
- Produces secondary xylem and secondary phloem
- Responsible for forming **woody tissues**

Cork cambium

- Produces cork
- Part of the bark tissue
- The outermost layer in **woody stems**

Formation of vascular cambium

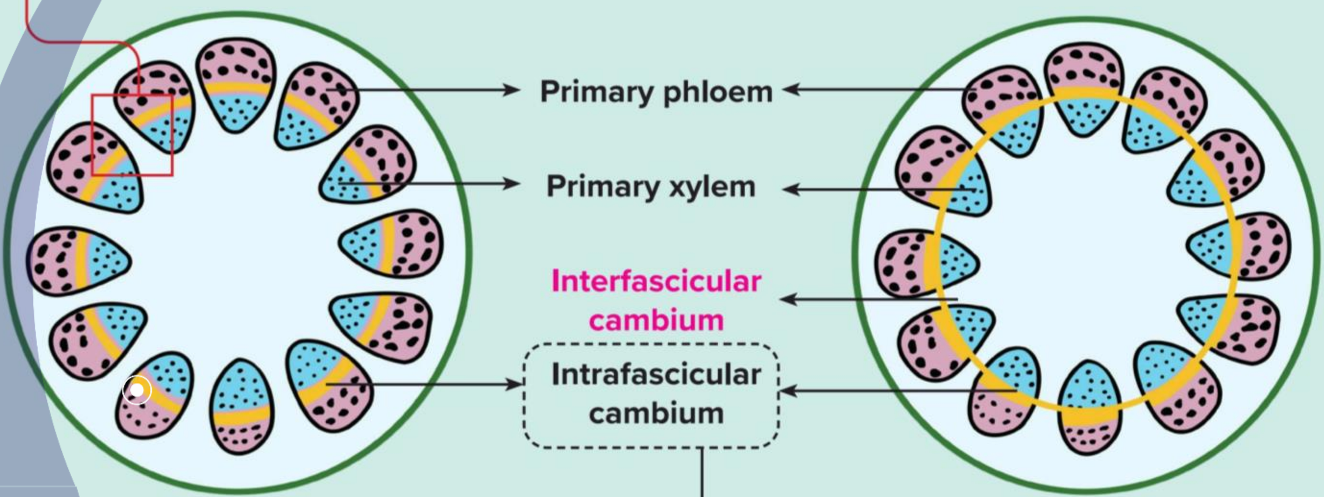
» **Intrafascicular cambium:** Present within the vascular bundle, patchy or non-continuous cambium present between primary xylem and primary phloem.

» **Interfascicular cambium:** The cells of medullary rays adjoining the intrafascicular cambium become meristematic and form the **interfascicular cambium**.

- The interfascicular and intrafascicular cambium together form the **cambial ring** (vascular cambium).

Medullary rays, which are strips of parenchyma cells, are present in young dicots that **dedifferentiate** to form interfascicular cambium.

Young herbaceous dicot stem has a layer of **vascular cambium** separating primary xylem and primary phloem known as intrafascicular cambium.

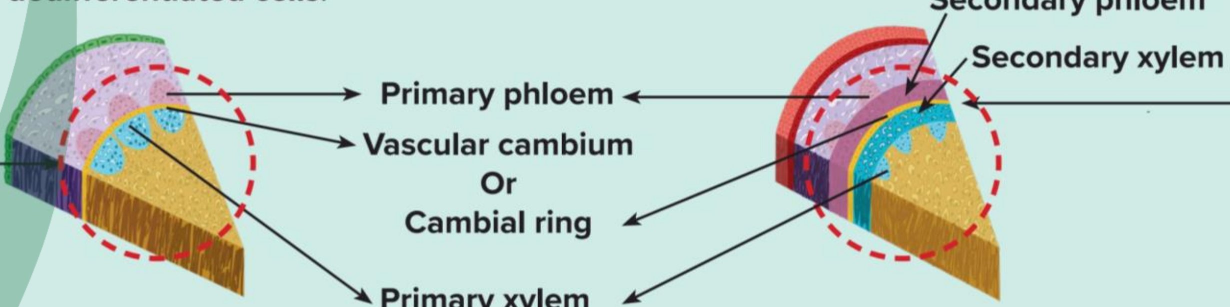


Herbaceous dicot stem

Formation of cambial ring

Interfascicular + Intrafascicular = Cambial Ring = Meristematic activity regained

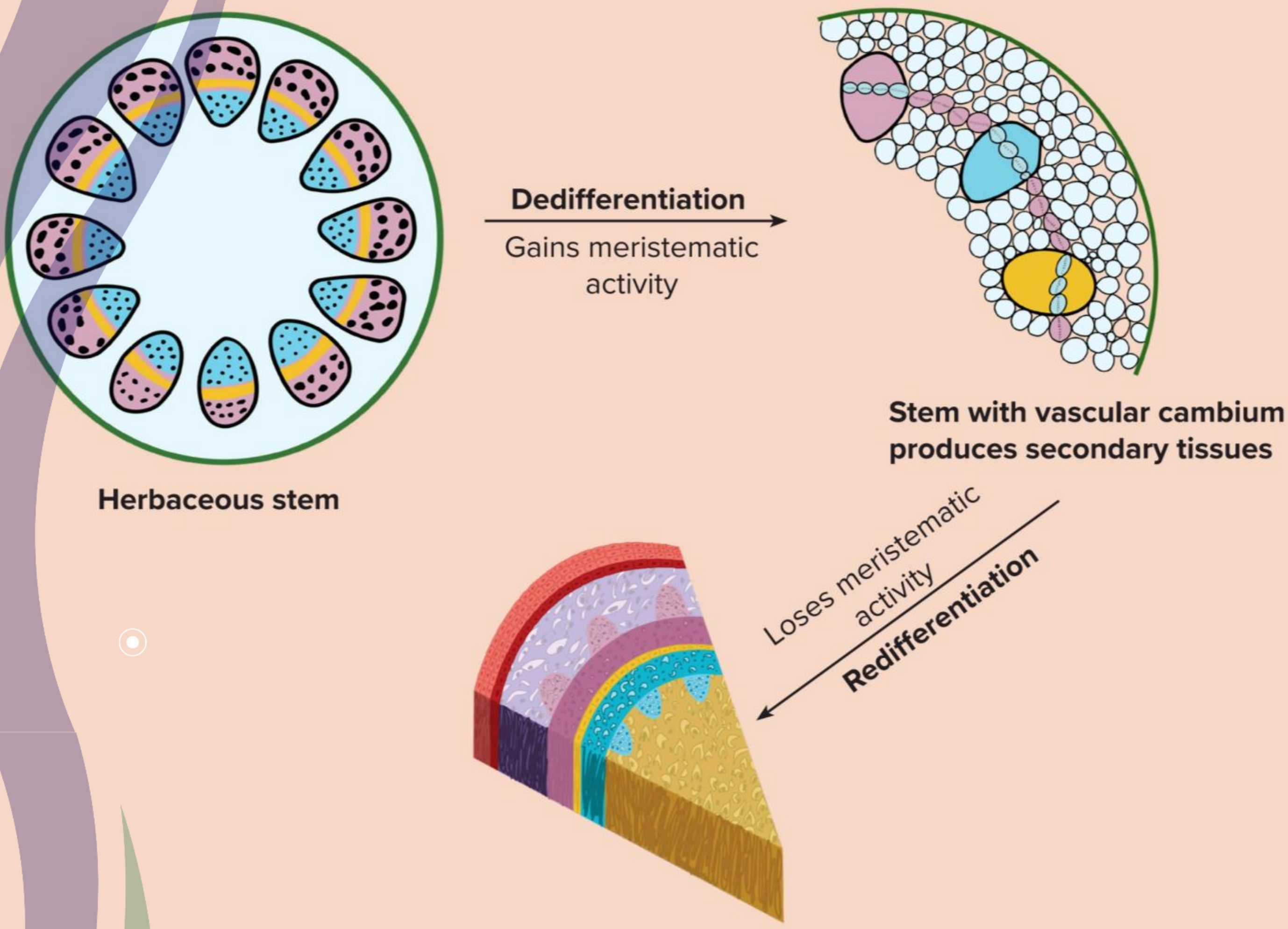
- The living differentiated parenchymatous cells lose the capacity to divide.
- They regain the capacity of division under certain conditions.
- This phenomenon is termed as **dedifferentiation** and these cells are called **dedifferentiated cells**.



- The cambium (formed due to dedifferentiation) cuts off on both sides. The outer side or towards the periphery leads to the **formation of secondary phloem**.
- Towards the inner side (or pith), gives rise to **secondary xylem**.
- It increases the **girth** of the plant.
- These dedifferentiated cells again differentiate to form secondary xylem and secondary phloem, i.e., **redifferentiate**.

Redifferentiation

- After dedifferentiation, the cells lose their meristematic activity and become specialised once again. **Differentiation of dedifferentiated tissues** is known as **redifferentiation**.
- Cells **again lose their capacity to divide** but become mature to perform specific functions.
- The process during which the dedifferentiated meristematic cells (cambial ring) again lose their meristematic activity (secondary tissues: secondary xylem and secondary phloem) is known as redifferentiation.



Meristematic cell

↓ **Differentiation**

Permanent cell

↓ **Dedifferentiation**

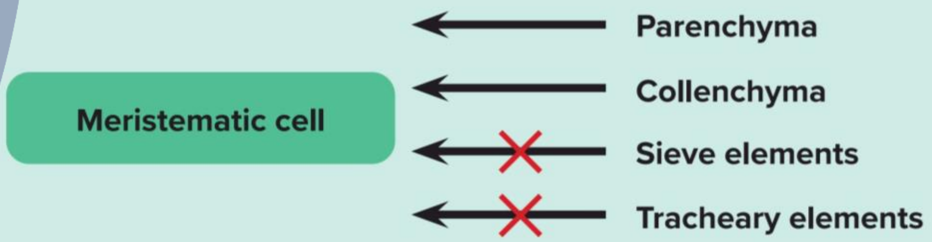
Meristematic cell

↓ **Redifferentiation**

Permanent cell

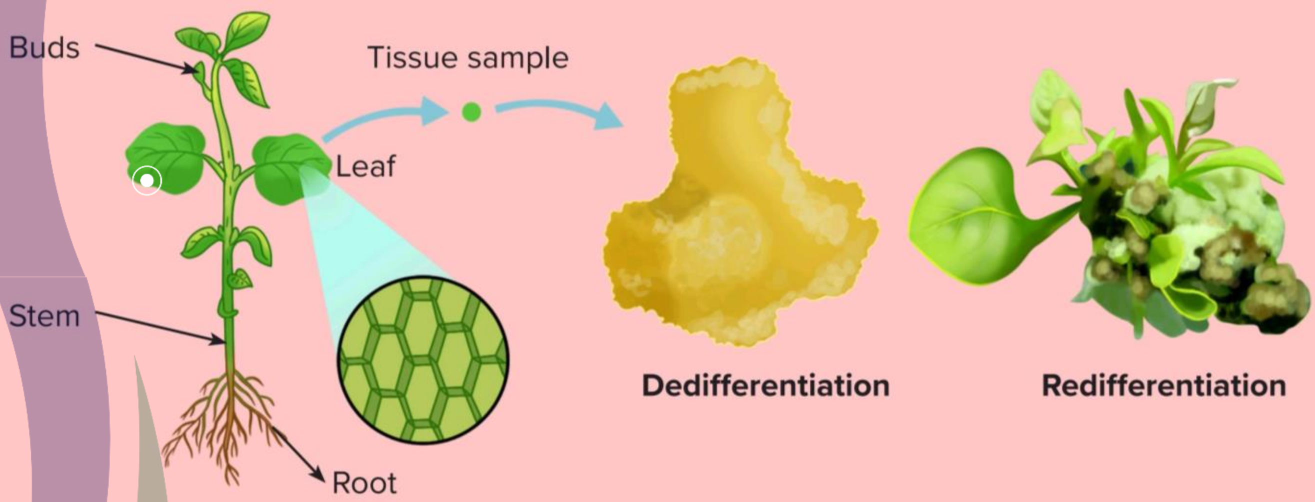
Not all cells can dedifferentiate

- The differentiated cells that have lost their nucleus and those that are dead at maturity cannot dedifferentiate.
- They are not able to generate into a complete plant as they do not have the required genetic information.



Did you know?

Dedifferentiated cells redifferentiate to give rise to a whole new plant.



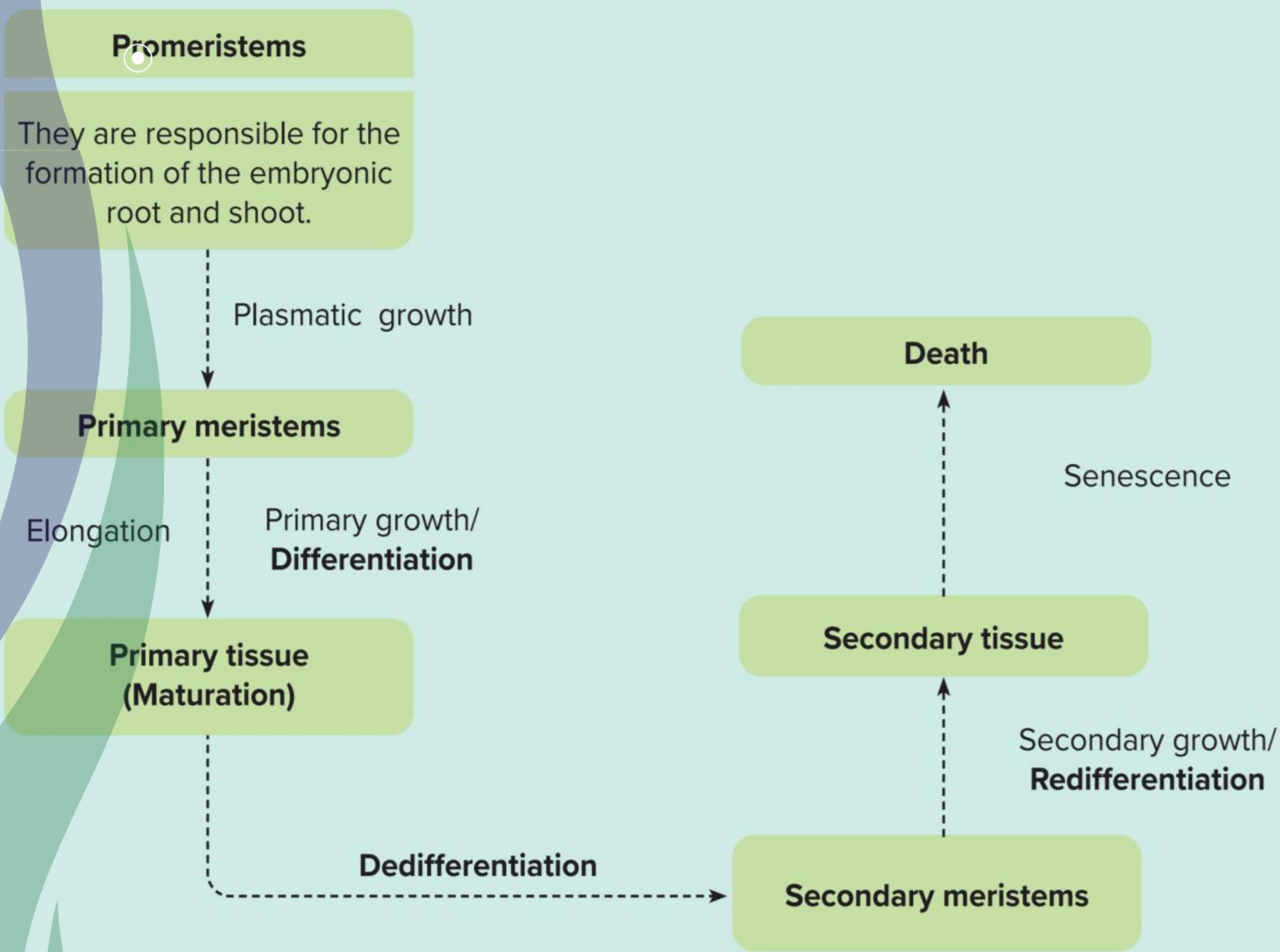
Growth vs Plant Development

- **Growth** is an **irreversible** and **permanent increase in the size** of an organ, an organ's parts, or an individual cell.

Growth

- **Plant development** includes all changes that an organism goes through during its life cycle **from germination of the seed to senescence**.
- Development and growth are sometimes used interchangeably.
  - » However, botanically, they describe separate events in the organisation of the mature plant body.

Plant development



Senescence

- It is a **biological process** of **deterioration with age**.
  » Cells lose the ability to divide and grow. Slowly, they tend to die.

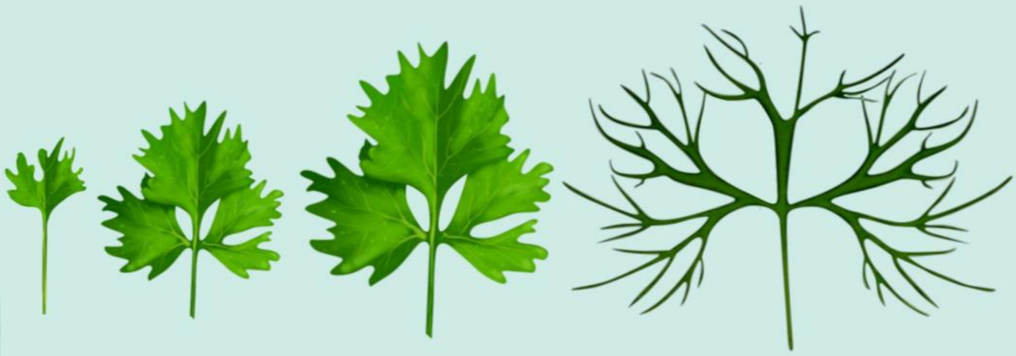
Did you know?

Plants can alter their development: Plasticity

- In response to the following:
  » Environmental conditions
  » Different phases of life
- Example: Heterophylly

Heterophylly

- Production of **different leaf forms** on the **same plant** during:
  » **Different phases of its life cycle**

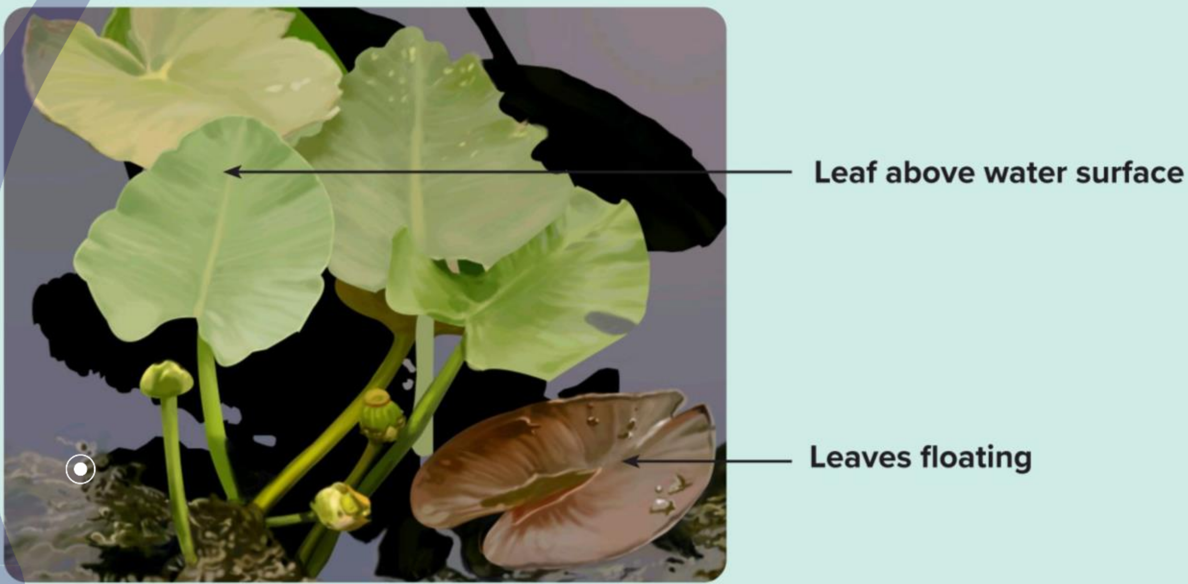


Plasticity: Heterophylly

- Example: **Cotton**

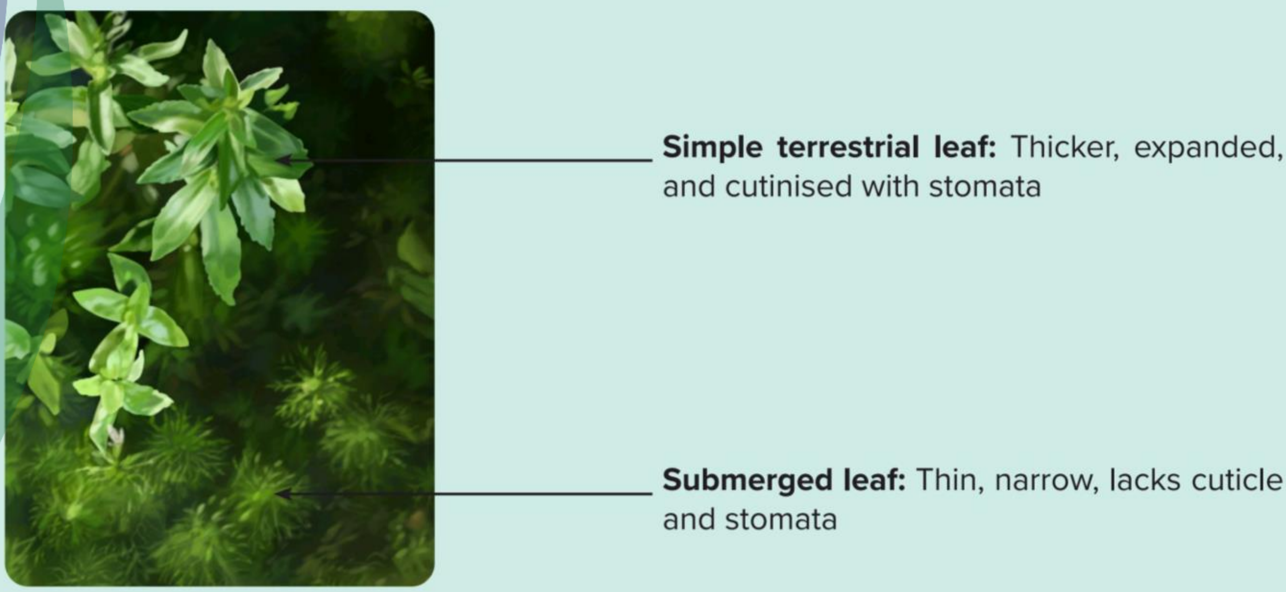
- Example: **Coriander**

- **Due to environmental conditions**
  - Example: *Nymphaea odorata*

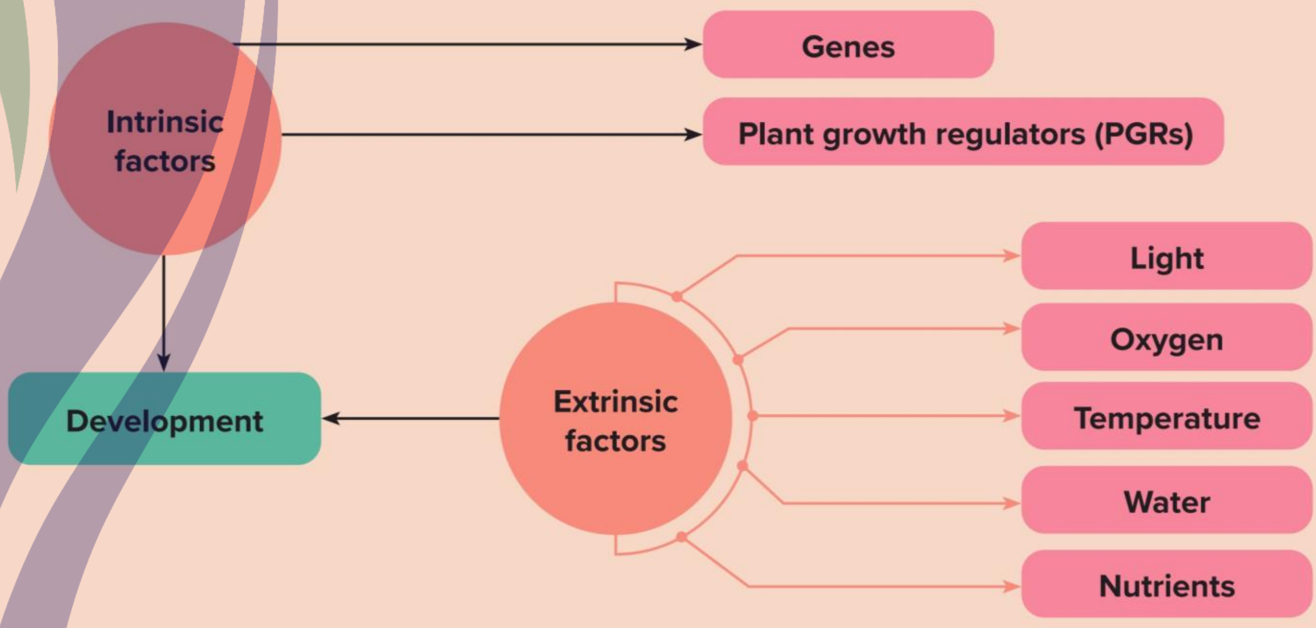


In American water-lily, an aquatic plant, the form of leaves switches from surface leaves in the early season to aerial leaves in the midseason and then back to surface leaves at the season's end due to **light.**

  - Example: *Limnophila heterophylla*



Plant development: Factors affecting plant growth



Intrinsic factors: Plant growth regulators

- Plant growth regulators or phytohormones are the simple molecules present inside the cells that control the **plant growth**.
- Phytohormones are **organic compounds** that signal, regulate, and control the growth of plants.
- Every plant cell can produce these hormones under appropriate conditions.

Types of phytohormones

Carotenoid derivatives

Plant pigments with yellow to orange colours

Abscisic acid

Adenine derivatives

They have adenine group.
Example: **Cytokinins** (N6-furfurylamino purine, kinetin)

Adenine group

Terpenes

They are aromatic compounds.
Example: **Gibberellic acids**

Terpene group

Indole group

They have an indole group as the core structure.
Example: **Auxins** (Indole-3-acetic acid)

Indole group

Gases

Example: **Ethylene**

Types of phytohormones (based on functions)

Growth promoting	Growth inhibiting
• Cell division • Cell elongation • Tropic growth • Organ development • Formation of reproductive structures • Flowering • Seed formation • Fruiting	• Dormancy • Stress tolerance (Biotic and Abiotic) • Abscission

Summary Sheet

Meristematic cell → **Differentiation** → **Permanent cell**

- The cells derived from root apical and shoot apical meristem differentiate to perform specific functions.
- During differentiation, cells undergo structural changes in the cell wall and protoplasm.
  Example: Tracheary elements lose their protoplasm and develop strong, elastic, and lignocellulosic secondary cell walls to carry water to long distances even under an extreme tension.

Permanent cell → **Dedifferentiation** → **Meristematic cell**

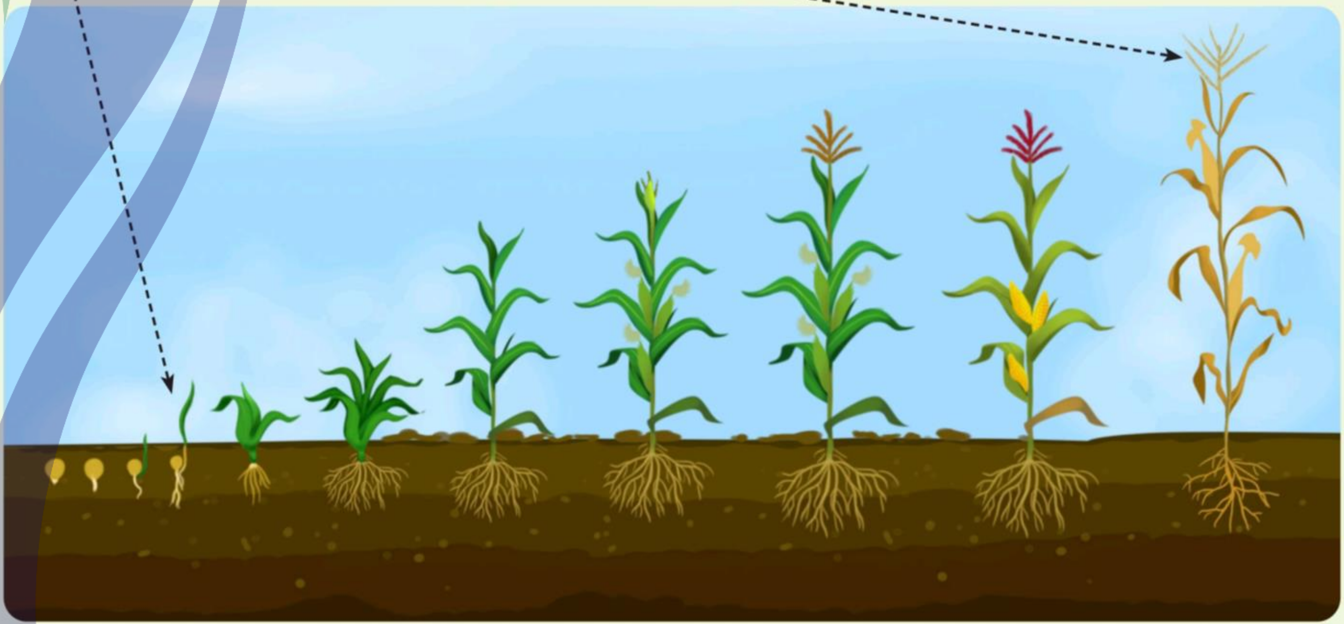
- After differentiation, the living differentiated cells, which have lost the capacity to divide, can regain the capacity of division under certain conditions.
  Example: Formation of interfascicular cambium and cork cambium

Meristematic cell → **Redifferentiation** → **Permanent cell**

- After the process of dedifferentiation, the produced cells again lose the capacity to divide and perform specific functions i.e., they get redifferentiated.
  Example: Secondary xylem, secondary phloem

Plant development

Includes all changes that an organism goes through during its life cycle from **germination** of the seed to **senescence.**



Plant hormones

Phytohormones or **plant growth regulators** are organic compounds that **signal, regulate,** and **control the growth of plants**.

Types of phytohormones

- Carotenoid derivatives
- Adenine derivatives
- Terpenes
- Indole compounds
- Gases

Phytohormones

Growth promoting

- Cell division
- Cell elongation
- Tropic growth
- Organ development
- Formation of reproductive structures
- Flowering
- Seed formation
- Fruiting

Growth inhibiting

- Dormancy
- Stress tolerance (Biotic and Abiotic)
- Abscission

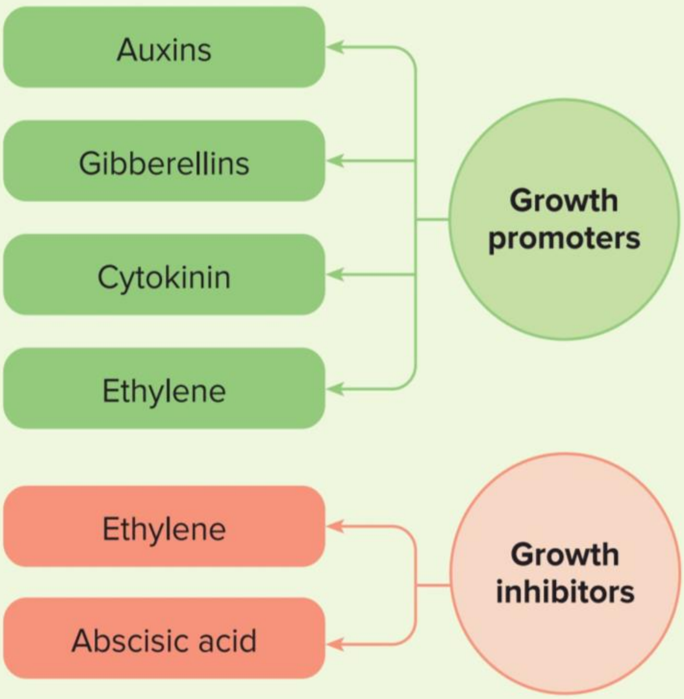
AUXIN, GIBBERELLIN AND CYTOKININ: DISCOVERY, CHARACTERISTICS AND PHYSIOLOGICAL EFFECTS

Key Takeaways

- Phytohormones
  - Auxin
  - Gibberellin
  - Cytokinin

Prerequisites

- **Phytohormones:** Organic components that signal, regulate, and control the growth of plants.

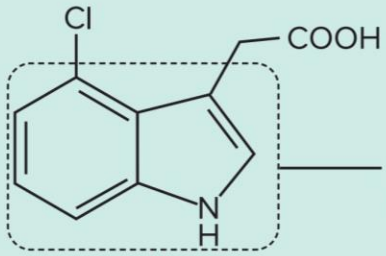


Did you know?

- The 5 major phytohormones were discovered **accidentally**.
  - Auxins
  - Cytokinins
  - Gibberellins
  - Ethylene
  - Abscisic acid

Auxins

- Auxin originated from the Greek word "*Auxein*" meaning "*to grow*".
- It is an **indole derivative** plant growth regulator.
  - Indole has a bicyclic structure, consisting of a benzene ring fused to a five-membered ring.



Structure of auxin - indole acetic acid

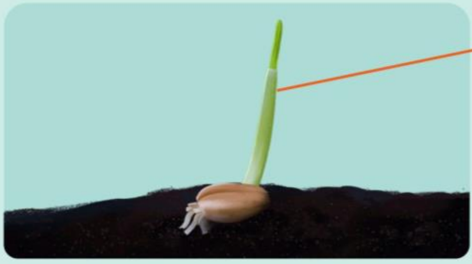
Discovery of auxins

Darwin's experiment

- Presence of a growth stimulator in the tip of the stem was discovered by Charles Darwin and his son Francis Darwin.
- Experiment was performed using canary grass (***Phalaris canariensis***).

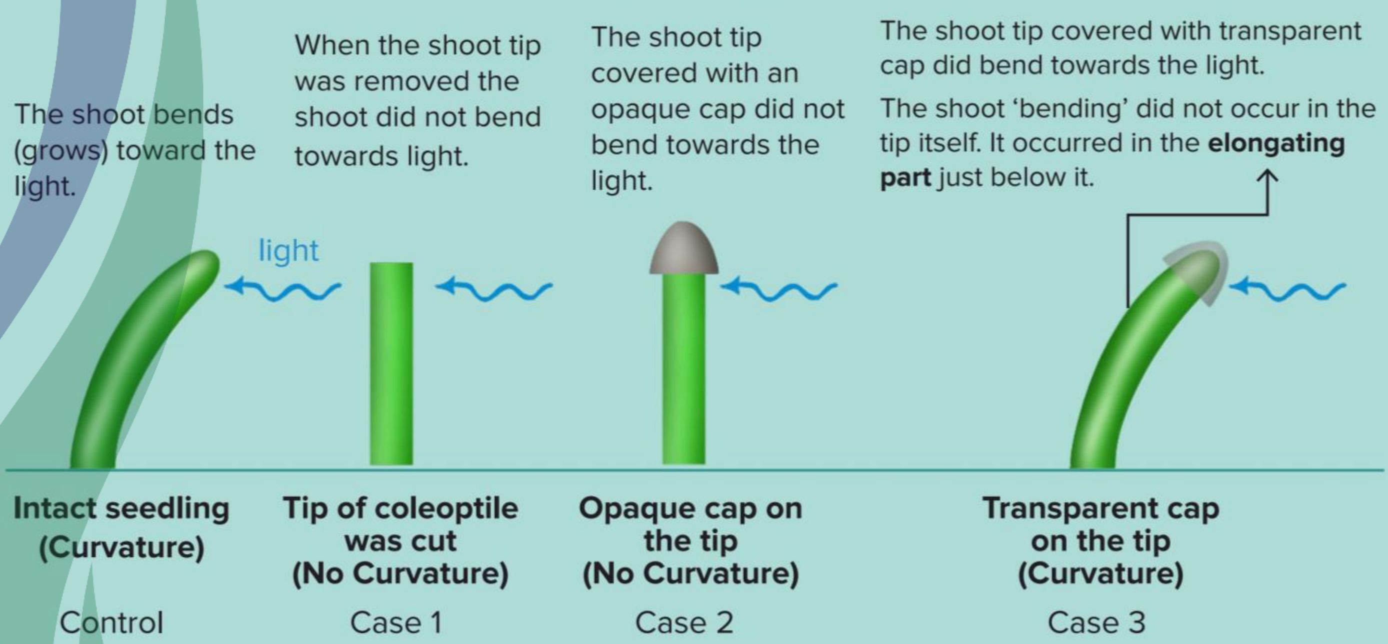
Hypothesis

- The **coleoptile tip** of the plant senses light.



Coleoptile: Protects the emerging young shoot and leaves during germination.

Observations:



Conclusions

- **Coleoptile tip** contains some **signal** that senses the light
- The signal is responsible for the "**bending**" of the coleoptile.

Went's experiment

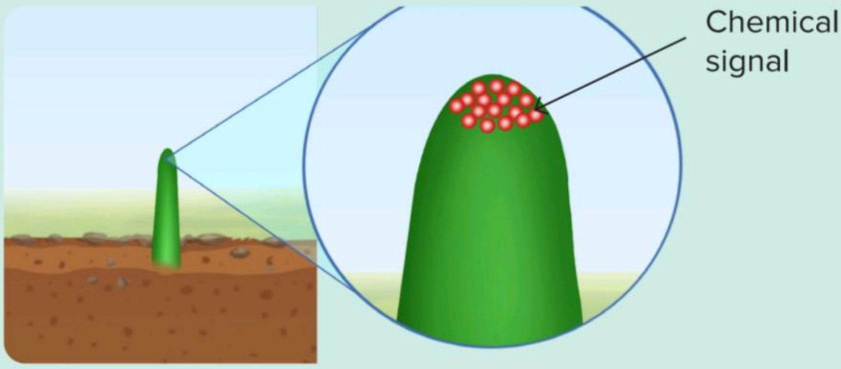
- **Frits W. Went** performed this experiment using oats ***(Avena sativa)*** in 1926.
- Went discovered the **chemical responsible for bending of plants towards light**.
- This test is known as **Avena curvature**.
- Went isolated **auxin** from the tips of coleoptiles of oat seedlings.
- Went hypothesized that there is the presence of a growth promoting factor (named as auxin) at the tip of the plant which caused its bending.

Avena sativa
(Oat plant)

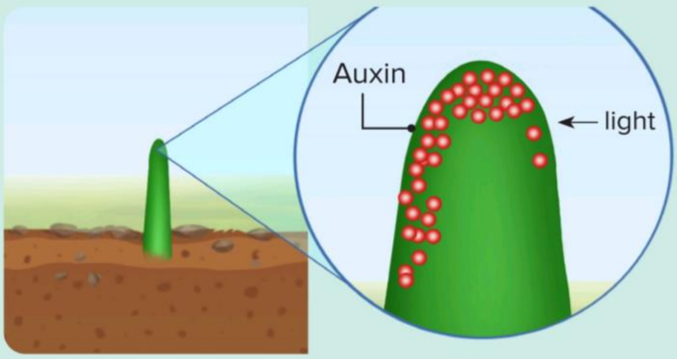
'Avena curvature'
Oat plant
Bending of plant

Conclusions

- **Elongation of cells** causes bending of the coleoptile.

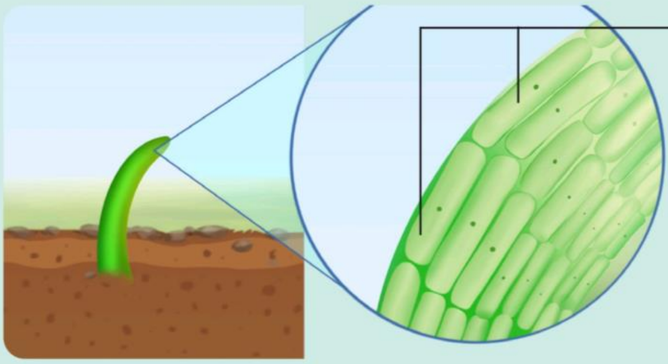


- Light stimulates auxin to move towards the shady region.



- This creates a concentration gradient where the auxin will be more in the shady regions, compared to the regions illuminated with light.

- The **cells in the shady region elongate faster compared to its opposite side**, resulting in the bending of the tip away from the shady region towards the light.



Types of auxins

Natural auxins

- These are produced naturally by plants.
- Example:
  Indole-3-acetic acid (IAA)
  Indole-3-butyric acid (IBA)
  4-chloroindole-3-acetic acid

Synthetic auxins

- These are synthesised.
- Example:
  Naphthalene acetic acid (NAA)
  2, 4-dichlorophenoxyacetic acid
  2, 4, 5-trichlorophenoxy acetic acid

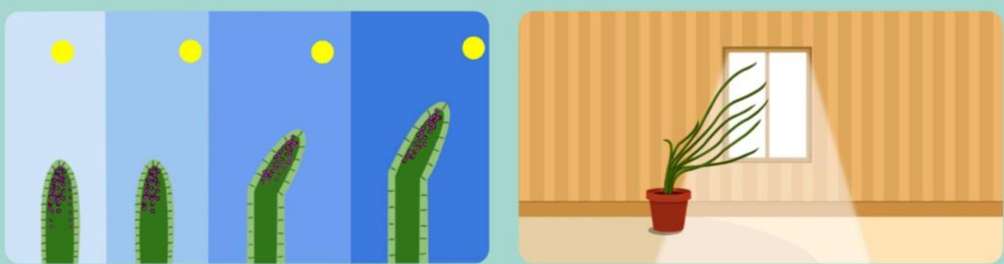
Functions of auxins

- Tropical movements
- Developmental effects

Tropical movements

Phototropism

- Phenomenon of plants bending **towards light**

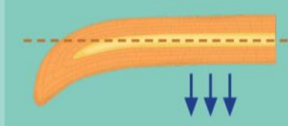


Gravitropism

- Phenomenon of coordinated growth of plants in response to gravity

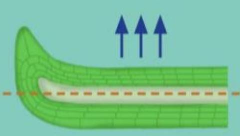
Positive gravitropism (Root tip)

- Towards gravity
- Auxin suppresses growth in the roots
- High concentration of auxin seen at the lower side
- Cell elongation takes place at the opposite side i.e., upper side
- Root tip **bends downwards**

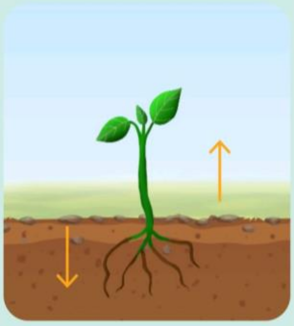


Negative gravitropism (Shoot tip)

- Opposite to gravity
- Auxin promotes growth in the shoots
- High concentration of auxin seen at the lower side
- Cell elongation takes place on the lower side
- Shoot **bends upwards**



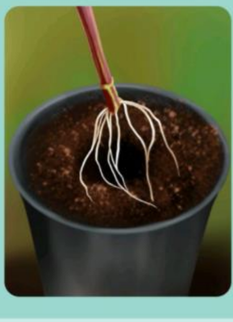
	Phototropism	Gravitropism
Shoot	+ve	-ve
Root	-ve	+ve



Developmental effects

Root initiation

- Promotes lateral and adventitious roots
- Initiates **rooting** in stem cuttings
  - ➜ Plant propagation



Flower initiation

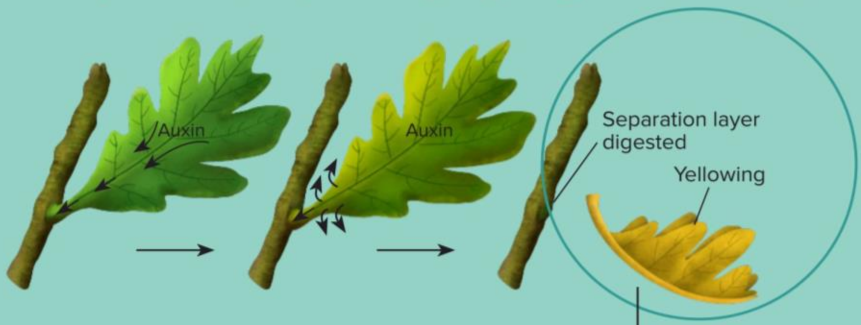
- Promotes flowering


Pineapple


Lychee plant

Prevention of abscission

- Auxin **delays abscission** (shedding of young leaves, flowers, fruits)



Auxin **delays abscission** (shedding of young leaves, flowers, fruits)

Yet helps in shedding of **mature fruits and older leaves**

Parthenocarpy

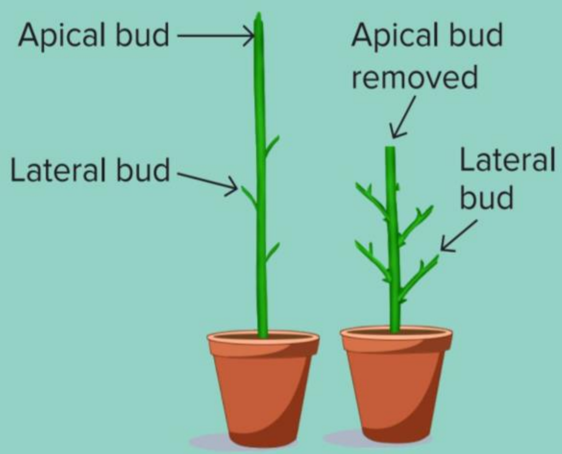
- Production of seedless fruits
  - ➜ Indole acetic acid can be used


Seedless Tomato


Seedless Watermelon

Apical dominance

- Adaptive features seen in plants where the auxin produced in the apical buds prevents the growth of the lateral buds
  - ➔ The growth of the main stem (central) is **dominated over the lateral stems**.



- Growth is vertical.
- *Araucaria heterophylla* shows **strong apical dominance**.
  - ➔ Its main stem is predominant over its lateral stems.
- Weeping larch **grows laterally (lateral growth)** in which apical dominance is absent.
- **Importance of apical dominance:** More access to light to perform photosynthesis as they are taller.

Apical dominance

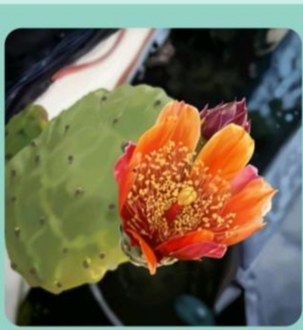
Araucaria heterophylla

Lateral growth

Weeping larch

Feminising effect

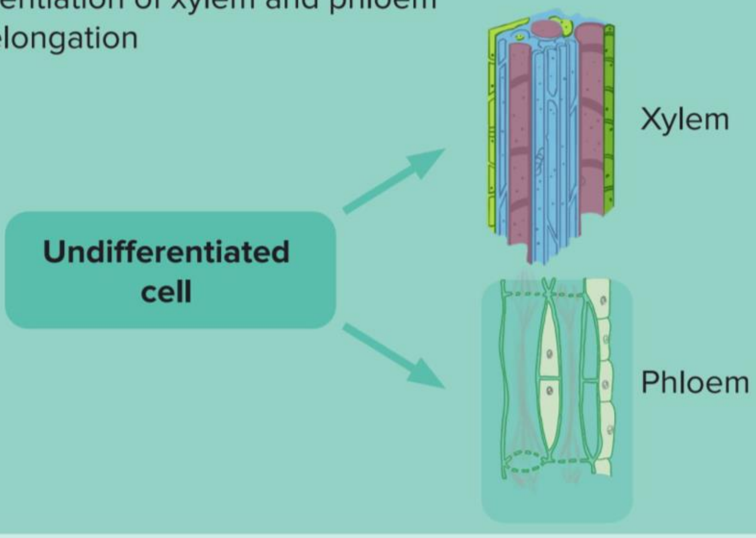
- Auxin has the ability to convert male flowers to female flowers in plants such as *Opuntia stenopetala* and *Cannabis sativus*.


Opuntia stenopetala


Cannabis sativus

Vascular differentiation

- Helps in
  - Differentiation of xylem and phloem
  - Cell elongation



Did you know?

- Auxins are dicotyledonous weed killers.
- It does not have any effect on mature monocots.
- 2, 4-dichlorophenoxy acetic acid and 2, 4, 5-trichloro phenoxy acetic acid were used to make the herbicide agent orange.

Gibberellins

- More than 100 gibberellins have been identified in a variety of plants.
- They are denoted as GA_1, GA_2, GA_3 and so on.
- **Characteristics:**
  - All GAs are **acidic**.
  - They are transported either through **xylem** or **phloem**.
  - They are formed in the **plastids** and then transformed in the endoplasmic reticulum and cytosol until they reach their biologically active form.

Discovery of gibberellins

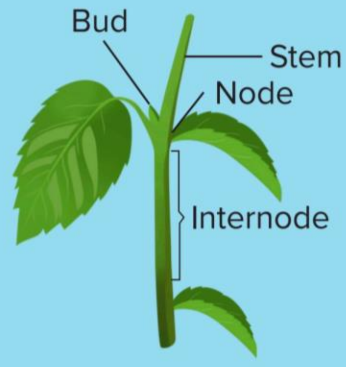
- Rice farmers in Asia had long known of a disease.
- It made the rice plants grow tall but declined seed production.
- This was called the "**foolish seedling**" or bakanae (baka means fool) in Japan.
- **E. Kurosawa in 1926** reported the symptoms of this disease.

- He reported that the symptoms appeared in seedlings on treatment with a fungus filtrate.
- The chemical obtained from the sterile filtrate of those tall parts was named as **gibberellin** (after *Gibberella fujikuroi*, the name of the fungus).
- The chemical compound is gibberellic acid which **induces tallness**.

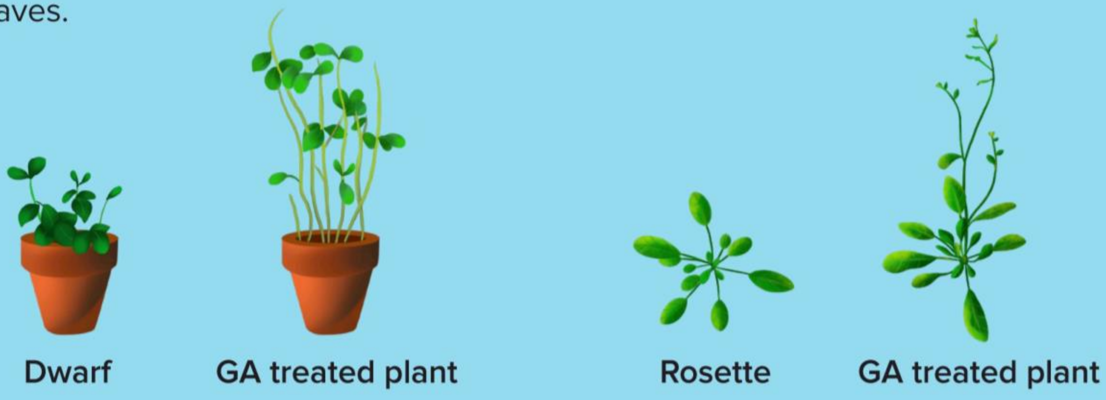
Functions of gibberellins

Stimulates stem growth

- Gibberellin induces **rapid cell division and cell elongation**.
- Stem growth is increased by **internodal elongation** in a wide range of species.
- **Bolting:** Internal nodal elongation prior to flowering is seen in plants like beetroots, cabbages, etc.
- External GA_3 application causes extreme stem elongation in dwarf plants.

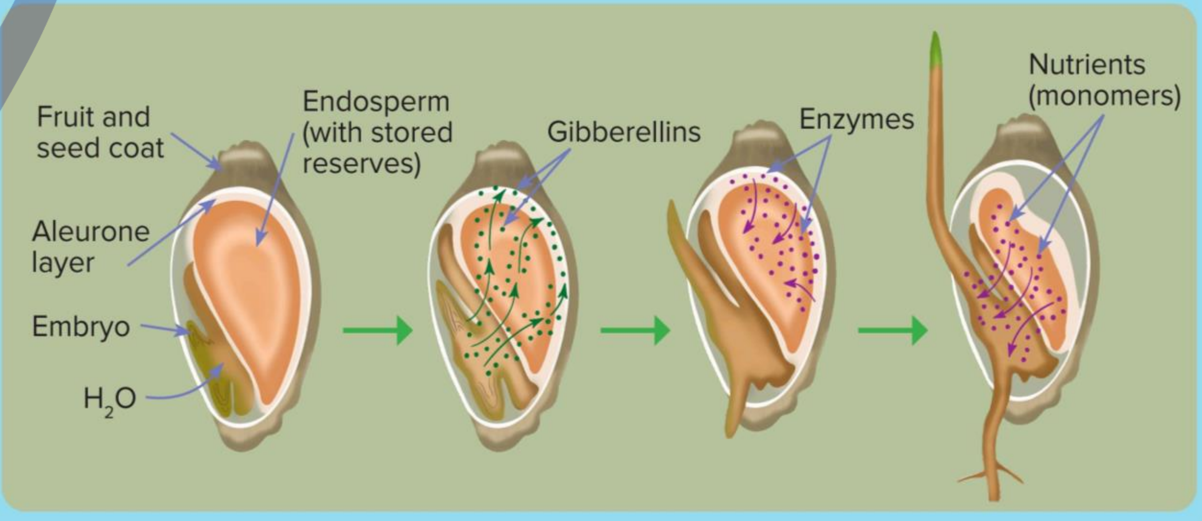


- Stimulates stem growth in rosette plants. Rosette is a circular arrangement of leaves.



Promotes seed germination

- During seed germination, the embryo imbibes water and swells.
- Embryo releases gibberellins and activates release of hydrolytic enzymes like **alpha amylase**.
- These enzymes move into the endosperm and digest the endosperm protein, starch to release the nutrients from which the embryo synthesizes new cells and starts germination.



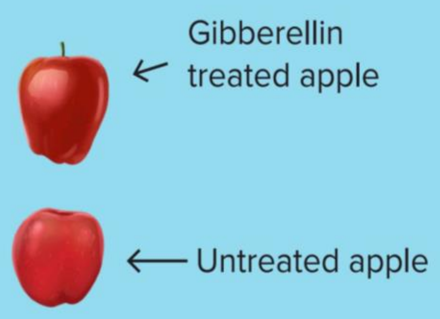
Delays senescence

- Delays the aging process in plants. GA is one of the anti-ageing hormones for plants.
- Prevents loss of **chlorophyll, RNA, proteins,** and **lipids**.
- Fruits can be left on the tree longer which helps in extending marketing period.

Uses of gibberellins

Increase in the length of grape stalk

Increases the stem length (sugarcane) and aids in yield enhancement



Elongated shape of apple

Speeds up malting process

Hastens maturity in juvenile conifers

Cytokinins

- These plant hormones are called cytokinins as they promote cell division or **cytokinesis**.
- Cytokinin along with auxin **promotes cell division**.
- Naturally occurring cytokinin tends to occur in regions of rapid cell division.
- They are transported via **xylem**.
- Some cytokinins **(synthetic)** have been reported to work as herbicides (Eg: benzyladenine and thidiazuron).

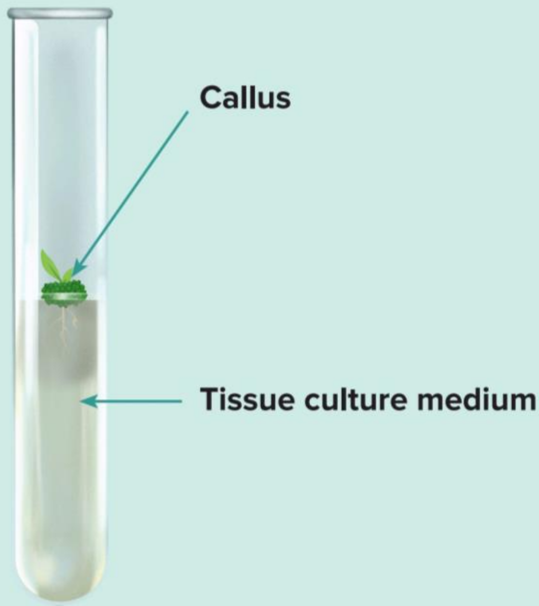
Discovery of cytokinins

F. Skoog's discovery

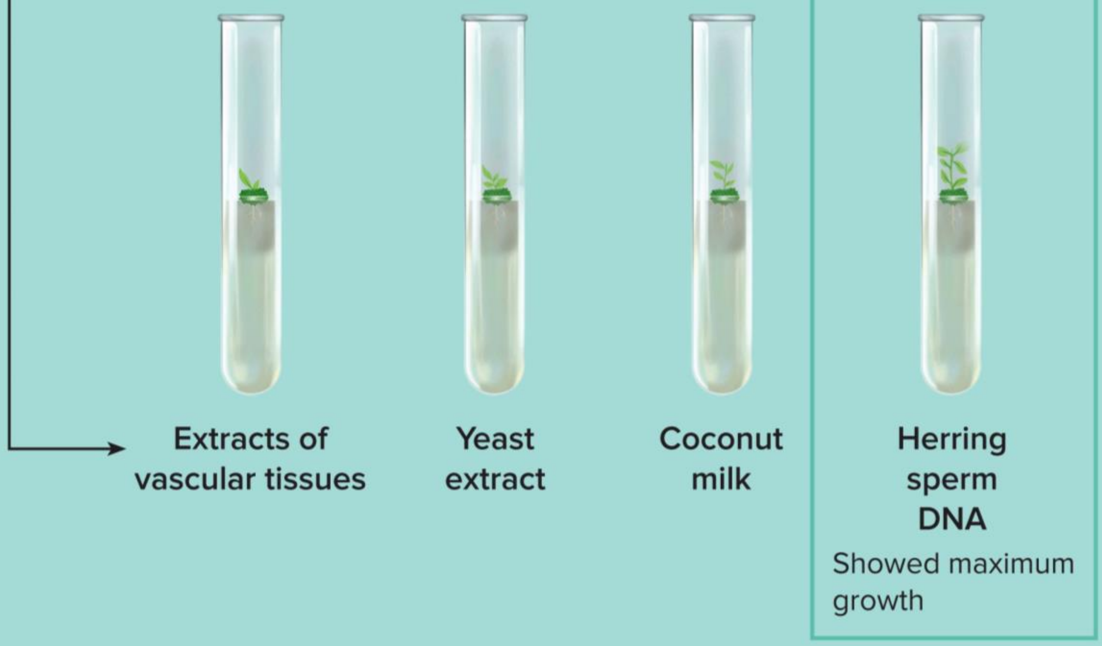
- Cytokinin was discovered while **F. Skoog** was working on **callus**.
- Callus is a **mass of undifferentiated cells**.

F. Skoog

- While working on tobacco proliferation, F. Skoog and his co-workers discovered that **along with auxins another 'material' leads to rapid cell proliferation (callus).**



F Skoog and his co-workers noticed that the growth of an undifferentiated mass of cells rapidly increased when other materials along with auxins were supplemented.



Observations

- Among all the test tubes, the test tube which had DNA showed maximum cell division.

Interpretation

- Tube with DNA had a powerful cell division promoting effect.
- The material was identified to be **adenine derivative**.
- **Kinetin**, modified adenine, was identified from the autoclaved DNA.
- Kinetin does not occur naturally in plants.

Conclusion

- Naturally occurring molecules with structures similar to that of kinetin regulate cell division activity within the plant.

C. O. Miller discovery

- Another chemical called **zeatin** was identified from the **maize kernel**.
- It is also an adenine derivative cytokinin.
- It was the **first naturally occurring cytokinin**.
- Miller extracted zeatin from maize endosperm.
- Since the discovery of zeatin, many naturally synthesised cytokinins have been discovered.

Functions of cytokinins

Regulates cell division

It is essential for cell division and it **promotes meristem growth**.

Cytokinins = More mitosis
More mitosis = More cells
More cells = Plant growth

Tumors

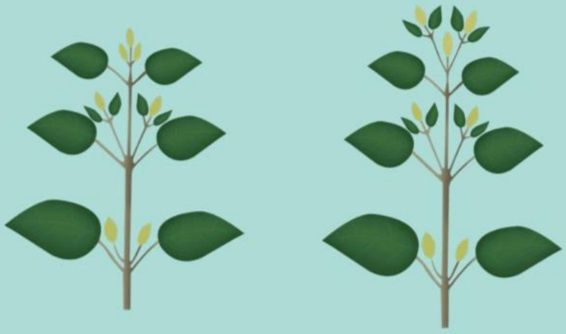
- Excessive cytokinin causes plants to **grow tumors** (similar to humans which are extra mass of cells).

Abnormal mass of tissue in humans.

Excessive cytokinin causes only cell division and no differentiation in plants.

Overcomes apical dominance and promotes lateral growth

- Cytokinin helps plants **overcome apical dominance**.
- It also initiates **growth of lateral buds**.
- Cytokinin aids in producing **bushy** plants.



Delays senescence

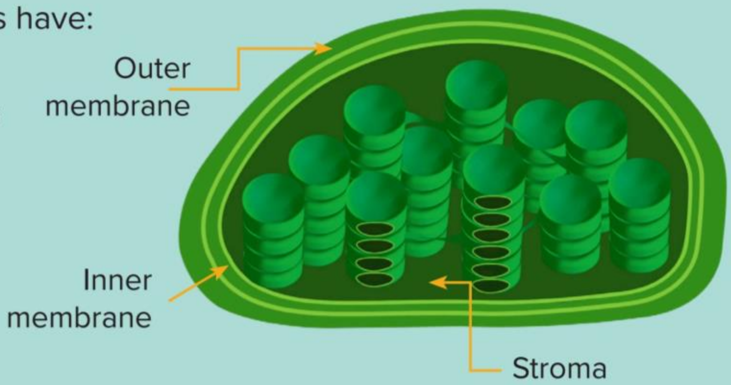
- Leaf **falling** and **yellowing** can be **prevented**.
- Prevents **loss of RNA, protein**, and **chlorophyll**.

Promotes nutrient mobilisation

- The nutrients move from one part to another part of the leaf.
- This is called **cytokine induced nutrient mobilization**.

Promotes chloroplast development

- Leaf treated with cytokinins have:
  - → Extensive grana
  - → Photosynthetic enzymes
  - → Chlorophyll



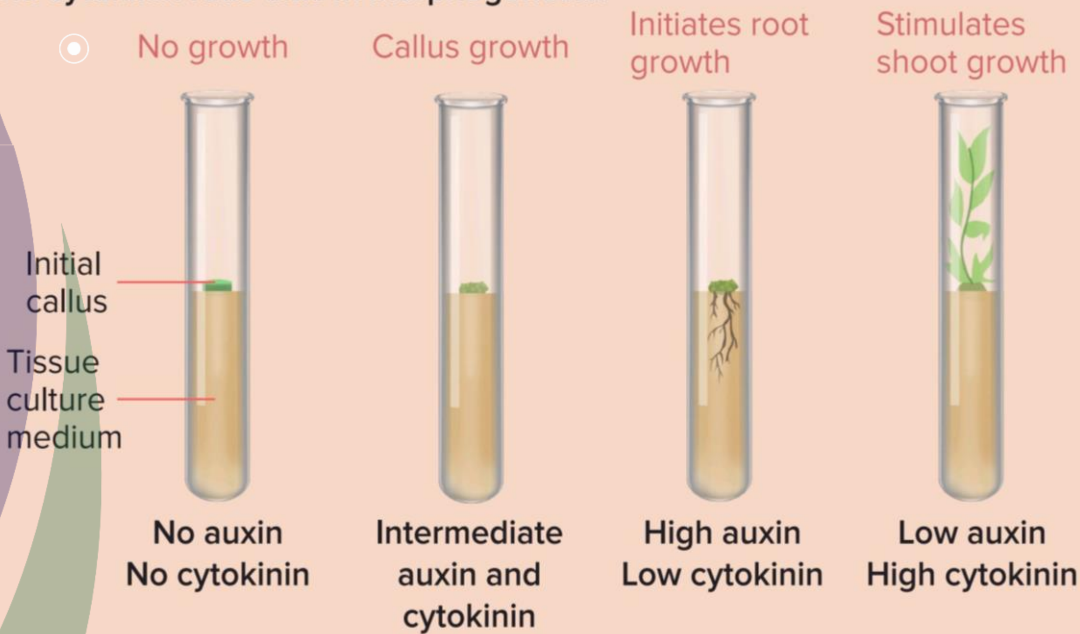
Helps to produce new leaves and shoots

Young Leaves

Adventitious shoots

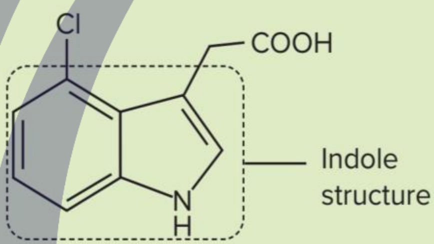
Did you know?

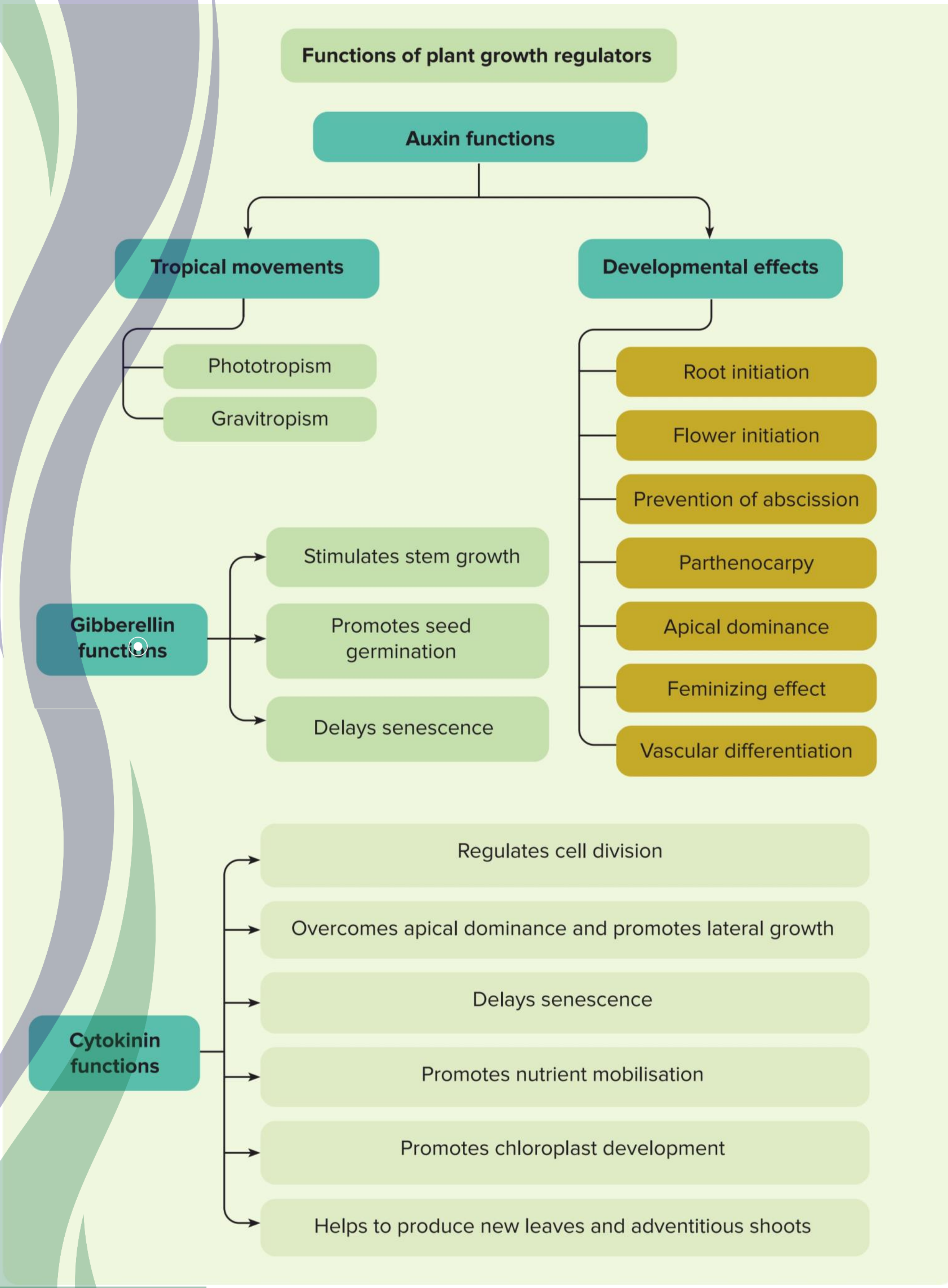
Auxin and cytokinin ratio aids in morphogenesis.



Summary Sheet

Plant Growth Regulators

Auxins	Gibberellins	Cytokinins
• **Indole derivative** plant growth regulators  **Discovery** • **Darwin**: Discovered the presence of some growth stimulator in the tip of the stem. • **Went**: Went hypothesized that there is the presence of a growth promoting factor (named as auxin) at the tip of the plant which caused bending towards light and he also isolated auxins. **Types** • Natural → IAA → IBA • Synthetic → NAA → 2,4-D	• All GAs are **acidic.** • Transported either through **xylem** or **phloem.** • Formed in the **plastids** • Example: GA_1, GA_2, GA_3 **Discovery** • **E. Kurosawa in 1926** reported the phenomenon (the "**foolish seedling**" or bakanae) in rice seedlings which makes the rice plants grow tall. • The chemical was later identified as **gibberellin** (after *Gibberella fujikuroi*, the name of the fungus).	• Plant hormones that promote cell division or **cytokinesis**. • They are transported via **xylem**. • Naturally occurring cytokinin - **zeatin**. • Synthetic cytokinin - **benzyladenine** and **thidiazuron** - used as herbicide. **Discovery** • **F. Skoog -** Cytokinin was discovered while F. Skoog was working on callus. • **Miller** - Identified another chemical called zeatin which promotes cell division.


Functions of plant growth regulators
Auxin functions
Tropical movements
Phototropism
Gravitropism
Developmental effects
Root initiation
Flower initiation
Prevention of abscission
Parthenocarpy
Apical dominance
Feminizing effect
Vascular differentiation
Gibberellin functions
Stimulates stem growth
Promotes seed germination
Delays senescence
Cytokinin functions
Regulates cell division
Overcomes apical dominance and promotes lateral growth
Delays senescence
Promotes nutrient mobilisation
Promotes chloroplast development
Helps to produce new leaves and adventitious shoots

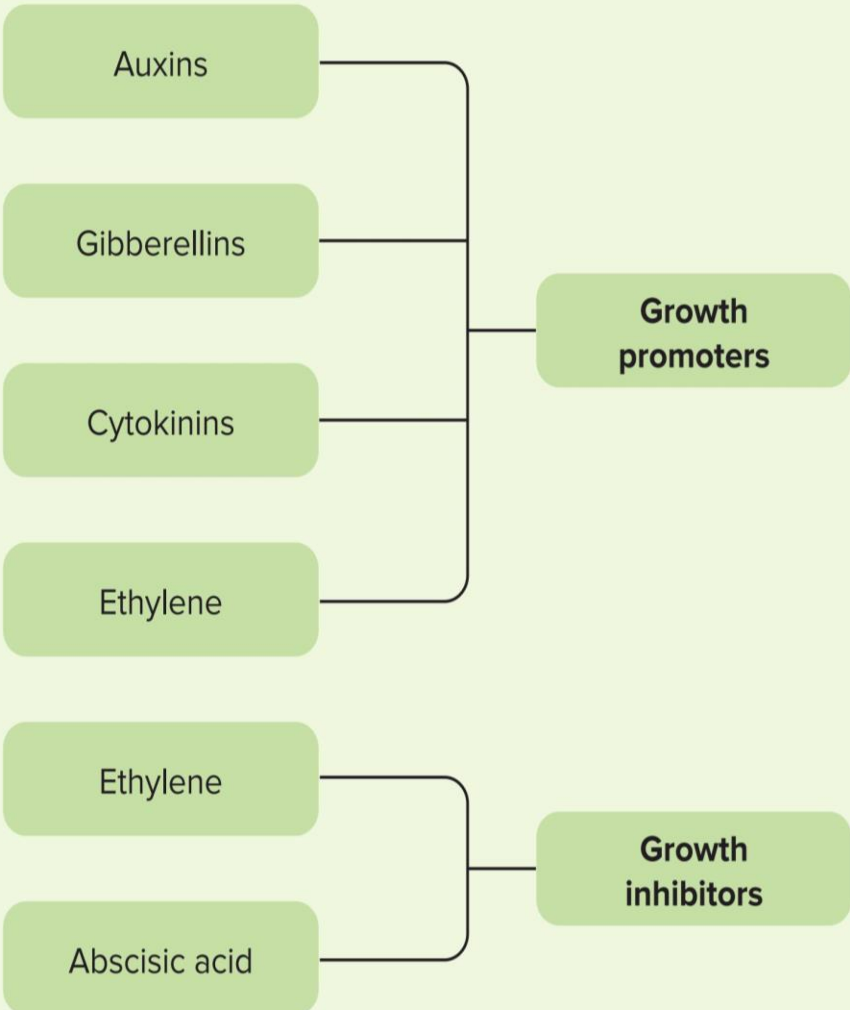
ETHYLENE: DISCOVERY, CHARACTERISTICS AND PHYSIOLOGICAL EFFECTS

Key Takeaways

- Ethylene
  - ➜ Effects of ethylene

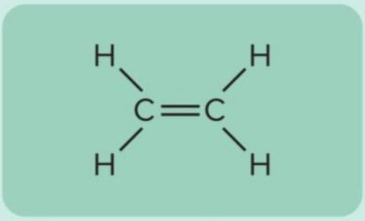
Prerequisites

- **Plant growth hormones (Phytohormones)**



Ethylene

- **Ethylene** is a **plant hormone** responsible for the **ripening** of many fruits.
- **H. H. Cousins** showed that ripened oranges hastened the ripening of stored unripened bananas.
- The spoiled oranges released a **volatile substance**, which was later identified as ethylene.
- The chemical formula of ethylene is C_2H_4 and its structure is given by,



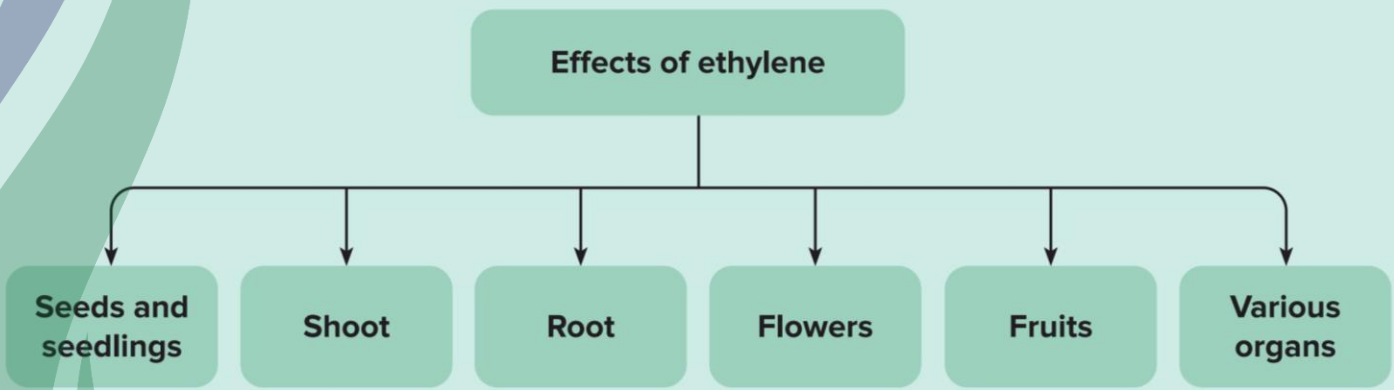
Ethylene structure

Did you know?

- During 1800 and early 1900s, **gas lamps** were used to light up streets.
- Flammable gases, such as coal gas, were used in these lamps.
- However, the use of these lamps was deadly for the nearby trees in the long run as it led to the falling of leaves, growth of strange branches, twisted and thickened trunks, growth of roots on stems, and death of many trees.
- Ethylene found in the gas was responsible for the devastation caused to the trees.

Effects of ethylene

- Ethylene has a **promoting effect** on all the stages of plant life starting from seed, the growth of the stem, flower, fruit, their maturation, and even senescence (aging).



Seed and seedlings

Breaks seed dormancy

- Some seeds do not germinate as they undergo dormancy for certain period.
- Ethylene breaks this dormancy and makes the seed ready for germination.

Germinating seeds

Initiates germination

- Ethylene stimulates germination along with gibberellins in some seeds. Example: Peanut

Horizontal growth of seedlings

- Ethylene promotes the horizontal growth of seedlings.

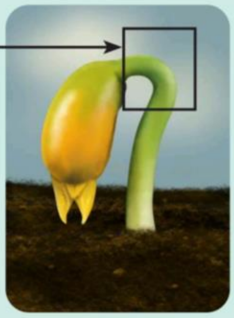
Swelling of embryonic axis

- Ethylene causes an increase in the girth of seedlings.

Ethylene concentration →

Apical hook formation

- Ethylene promotes the development of the apical hook in dicot seeds that prevents damage to the growing tip.



Shoot

Breaks bud dormancy

- Sometimes, buds in a plant get dormant due to unfavourable environmental conditions.
- Ethylene helps to break this dormancy.

Buds

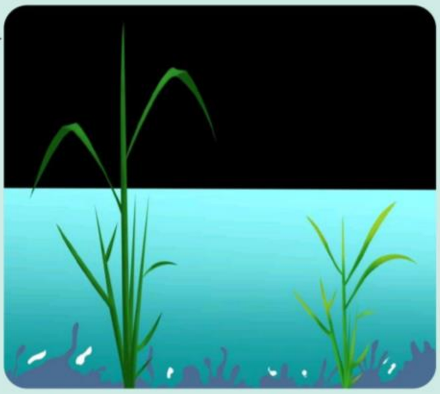
Sprouting of potato tubers

- Ethylene even breaks the dormancy of potato buds and promotes their growth.

Potato buds

Internode/Petiole elongation

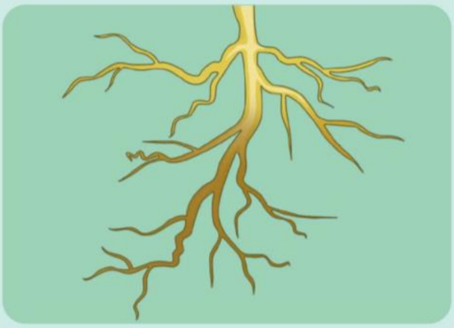
- Deepwater rice plants grow in Southeast Asia and India.
- They have evolved to tolerate huge quantities of water.
- Ethylene in these plants promotes the growth of internodes and petioles.
- The leaves and the upper parts of the plants remain above water and do not allow them to suffocate.



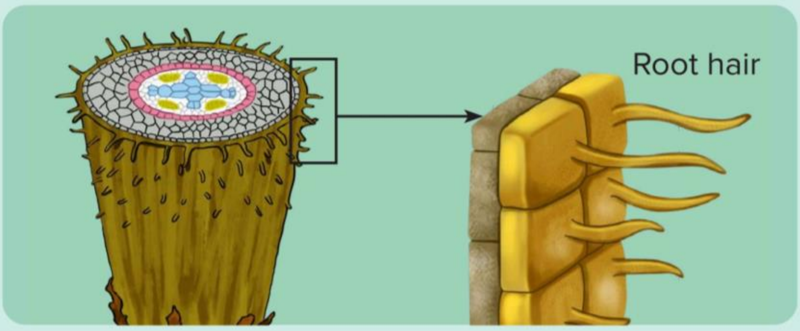
Deep water rice | Non-deep water rice

Root

Promotes root growth



Promotes root hair formation to increase the absorption



Flowers

Flowering in pineapples, mangoes

- It induces flowering in pineapples and mangoes.

Mango flowers

Promotes female flowers in cucumbers

- Cucumber has separate male and female flowers.
- Ethylene favours female over male flowers.
- It leads to an increase in cucumber yield.

Cucumber flower

Synchronises fruit set in pineapples

- Fruit set is the transition from flower to young fruit in the development of seed.
- Natural flowering in a pineapple plant is variable.
- Ethylene is used to make all the plants flower at the same time.
- It also leads to the production of fruits at the same time.

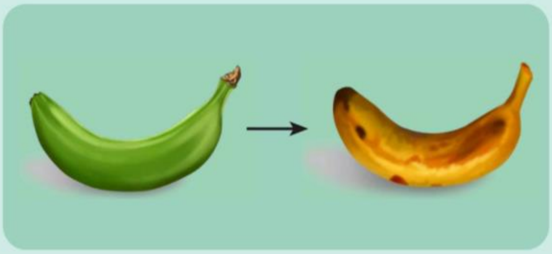
Pineapple fruit

Fruits

Ripening

- Ethylene is commercially used to ripen the foods.
  - **Ethephon** or **2-chloroethylphosphonic acid** is the source of ethylene.
  - The plants absorb ethephon and convert it to ethylene.

- Ethylene leads to **respiratory climacteric**.
  - Respiratory climacteric is the **concluding stage** of ripening process.
  - It is characterised by increased cellular respiration.
  - It is also the time when the colour changes from green to yellow, red, and more.
  - Sugars are released during this time in some fruits.



Colour changes from green to yellow

Various organs

Induces senescence

- The process of aging and decay in a plant is known as **senescence**.
- It can happen to any part of a plant.

Induces abscission

- It induces the process of shedding of the plant leaves, flowers, seeds, and fruits.
- Ethylene is used for **thinning** in agriculture.
  - Thinning means reducing the number of fruits or other plant parts so that the remaining ones can grow better.
  - **Ethephon** is usually applied to promote abscission which results in thinning.

Tricks to remember effects of ethylene

An **Absolutely Rich Ripe Old German Spinster**
Hung her **Embroidered Floral Sweater**
on a **Hook** behind a **Long Door**

An	**Absolutely**	Abscission
	Rich	Root and root hair growth
	Ripe	Ripening of fruits
	Old	Aging/Senescence
	German	Germination
	Spinster	Sprouting of potato tubers
	Hung	Horizontal growth of seedlings
her	**Embroidered**	Embryonic axis swelling
	Floral	Flowering
	Sweater	Synchronises fruit set
on a	**Hook**	Apical hook formation
behind a	**Long**	Elongation of internodes/petioles
	Door	Dormancy breaks in seeds/buds

Summary Sheet

Effects of ethylene

- **Seeds and seedlings**
  - Breaks seed dormancy
  - Initiates germination
  - Stimulates horizontal growth of seedlings
  - Causes swelling of embryonic axis
  - Promotes apical hook formation
- **Shoot**
  - Breaks bud dormancy
  - Helps sprouting of potato tubers
  - Promotes internode/petiole elongation
- **Root**
  - Promotes root growth
  - Promotes root hair formation

- **Flowers**
  - Induces flowering in pineapple, mango
  - Promotes female flowers in cucumber
  - Synchronises fruit set in pineapples
- **Fruits**
  - Helps in the ripening of fruits
- **Various organs**
  - Induces senescence
  - Induces abscission

ABSCISSIC ACID, SEED DORMANCY

Key Takeaways

- Abscisic acid (ABA)
  - Physiological effects
- Seed dormancy
  - Advantages of seed dormancy
  - Causes of seed dormancy
  - Methods to break seed dormancy

Prerequisites

- **Phytohormones**

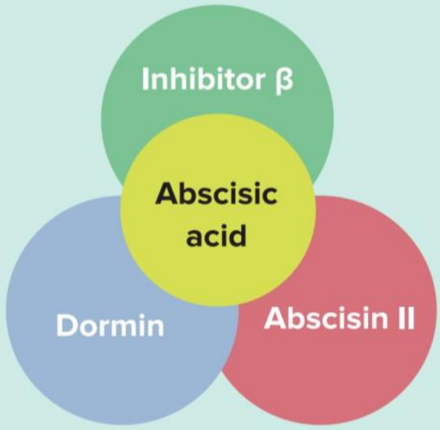
- Auxins, Gibberellins, Cytokinin, Ethylene → **Growth promoters**
- Ethylene, Abscisic acid → **Growth inhibitors**

Abscisic Acid (Stress Hormone)

Did you know?

- How do animals escape extreme weather conditions such as drought, cold, etc?
  - They escape by employing various methods like hibernation, aestivation, and migration.
- But how do plants escape extreme weather conditions or situation of stress?
  - **Abscisic acid** helps plants to overcome situations of **stress** and is, therefore, aptly known as the **stress hormone**.

- ABA is derived from **carotenoids**.
  - Carotenoids are plant pigments with yellow to orange colours.
- **Discovery of ABA**
  - In the 1960's different groups of scientists discovered various growth inhibitors such as **inhibitor β, abscisin II, and dormin**.
  - Later, it was proved that all the three growth inhibitors were chemically identical and were named **abscisic acid.**



Did you know?

Abscisic acid was named so because it was thought to promote abscission. However later it was found that this effect was seen in very few plants.

Note

The shedding of leaves, flowers, and fruits is known as **abscission**.

Physiological effects of abscisic acid

- It **increases the tolerance** of stressful environmental conditions, helping the plants cope with stress.

- It acts as **growth inhibitor for plants** by inhibiting the metabolic activities during unfavourable environmental conditions.
  - The rate of photosynthesis decreases during unfavourable conditions (like low light and non-availability of water), and plants survive on stored food.
  - In order to conserve energy, ABA acts to decrease the rate of metabolic activities, which inhibits the growth of the plant.

- It helps in **seed development** by the accumulation of reserved food, helping in the maturation of the seed.

- It **induces seed dormancy** and **inhibits germination** during unfavourable conditions*.

- It **stimulates the closure of stomata** during unfavourable conditions*, helping to **conserve water by minimising transpiration.**
- It acts as an **antagonist to gibberellins**. Gibberellin is a growth promoter and ABA is a growth inhibitor.

***Unfavourable conditions:** Conditions such as drought, extreme hot or cold, excessive water, etc.

Did you know?

- 2000-year old seeds of date palm, which were found in Israel, germinated in 2005 and gave rise to a healthy plant.
- The physiological phenomenon behind this is known as **seed dormancy.**

Seed Dormancy

- **Seed dormancy** means the lack of seed germination even during favourable conditions.
- It is **not controlled** by the **external environment** but by conditions within the seed itself **(endogenous control)**.

Advantages of seed dormancy

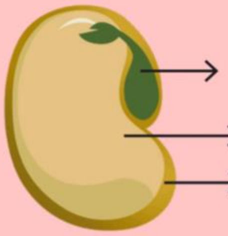
- Seed dormancy that leads to delayed germination allows time for the dispersal of seeds, **preventing the overcrowding of seedlings**.
- Seed dormancy **prevents germination during unfavourable environmental conditions** (conditions such as drought, extreme hot or cold, excessive water, etc).

Causes of seed dormancy

Causes of seed dormancy
- Impermeable or hard seed coat
- Chemical inhibitors
- Immature embryos

Impermeable or hard seed coat

- The impermeable seed coat does not allow the entry of water and oxygen, which leads to dormancy.



- The hard seed coat acts as a mechanical barrier to germination.

Chemical inhibitors

- Chemical inhibitors such as abscisic acid and phenolic acid present in the seeds prevent germination.

Immature embryos

- Some seeds are released by the plants before the embryo has fully matured.
- These seeds remain dormant until the embryo matures completely.

Did you know?

Svalbard global seed vault

- It is a long term seed-storage facility located halfway between the North pole and Norway.
- It has close to a million samples that includes the seeds of wheat, rice, and others. It acts as a seed reservoir.
- It is built to save the world from instances like food crisis.
- This long-term storage is made possible because of seed dormancy.

Svalbard global seed vault

Methods to break seed dormancy

Natural

- Hard and impermeable seed coats are broken by the following measures:
  - **Microbial action**
  - **The passage through the digestive system of animals**. This weakens the seed coat and promotes germination.

- **Chemical inhibitors** that lead to seed dormancy are often leached off from the seed by the action of **rainwater**.

Artificial

- The seed coat can also be broken by a process known as **scarification** (mechanical abrasion).
- Scarification can be done by **knives, sandpaper, vigorous shaking**, the action of harsh chemicals like **strong acids**, and **hot water.**

- The effect of inhibitory substances can be removed by subjecting the seeds to **chilling conditions.**

- The seed coat can be broken by the application of **certain chemicals** like **gibberellins, potassium nitrate, thiourea,** and others.

- Seed dormancy can be overcome by keeping them in the **refrigerator** for several weeks. A certain wavelength of light can also promote seed germination.

Summary sheet

- **Abscisic acid** helps plants to overcome situations of stress and are thus known as the **stress hormone**.
- They are derived from **carotenoids.**
- In the 1960's different groups of scientists discovered chemicals such as **inhibitor β, abscisin II, and dormin**, which were later confirmed as abscisic acid.

Effects of abscisic acids

- **Increases the tolerance** of stressful environmental conditions
- Acts as a **growth inhibitor for plants**
- Acts as **an inhibitor of plant metabolism**
- Helps in the **seed development and maturation**
- **Induces seed dormancy** and **inhibits germination**

- **Stimulates the closure of stomata**
- Acts as an **antagonist to gibberellins**

Advantages of seed dormancy*

- Prevents the **overcrowding of seedlings**
- Prevents germination during **unfavourable environmental conditions**

Causes of seed dormancy*

- **Impermeable or hard seed coat**
- **Chemical inhibitors**
- **Immature embryos**

Seed dormancy* refers to the lack of seed germination even during favourable conditions.

Methods to break seed dormancy

Natural

- Hard and impermeable seed coats are broken by the following measures:
  - **Microbial action**
  - **The passage through the digestive system of animals**
- **Chemical inhibitors** that lead to seed dormancy are often leached off from the seed by the action of **rainwater**

Artificial

- **Scarification** (mechanical abrasion)
  - Using **knives, sandpaper, vigorous shaking**, **strong acids**, and **hot water**
- **Subjecting the seeds to chilling conditions**
- Application of **certain chemicals** like gibberellins, potassium nitrate, thiourea, etc.

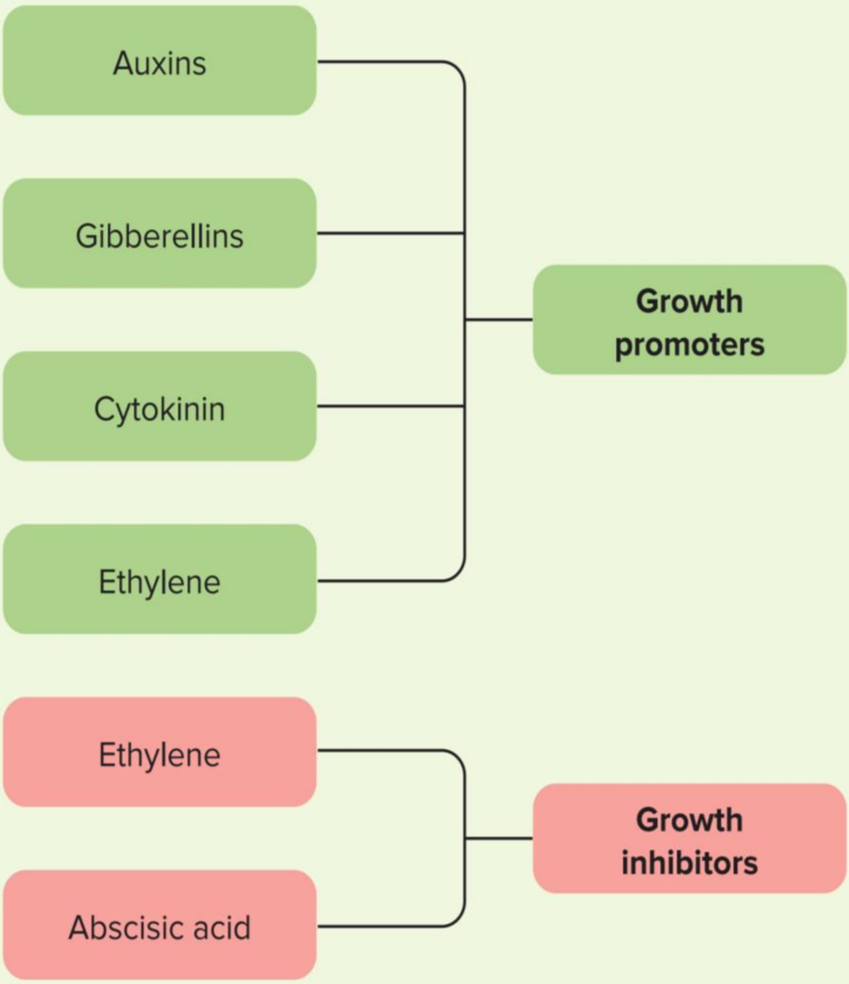
PHOTOPERIODISM, VERNALISATION, PLANT SENESCENCE AND ABSCISSION

Key Takeaways

- Photoperiodism
- Vernalisation
- Plant senescence and abscission

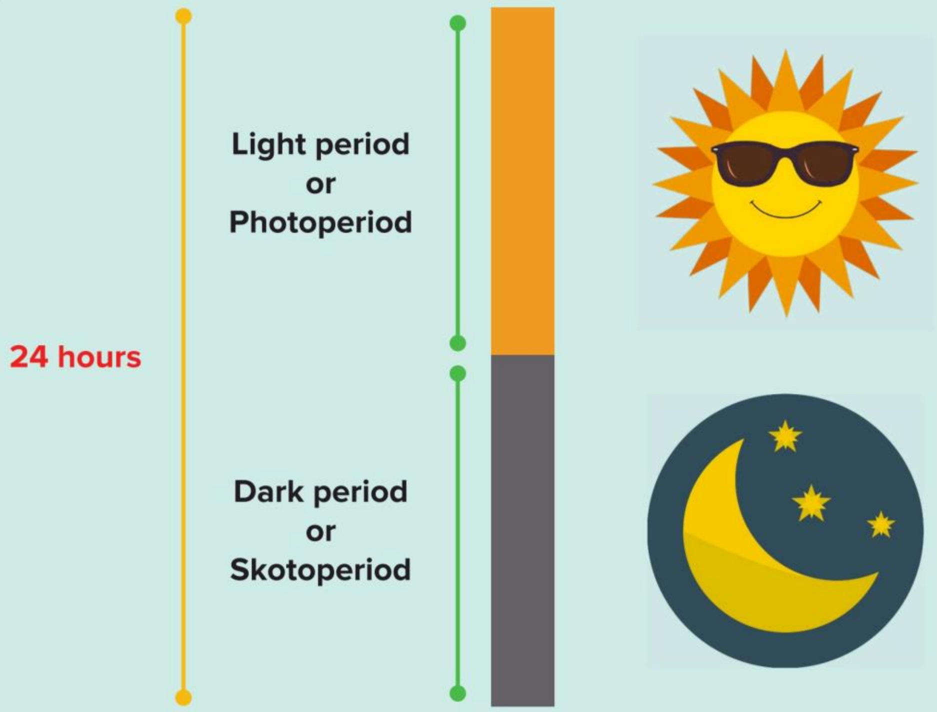
Prerequisites

- **Plant growth hormones (Phytohormones)**



Photoperiodism

- Photoperiodism is the response of plants to the relative length of day and night.
- It was first studied by **Garner and Allard** (1920).
  - To understand photoperiodism better, let us consider the timeline of an entire day, which is 24 hours.
  - A part of the day would experience light. This period is known as the **light period or photoperiod**.
  - The remaining part of the day would experience a **dark period or skotoperiod**.

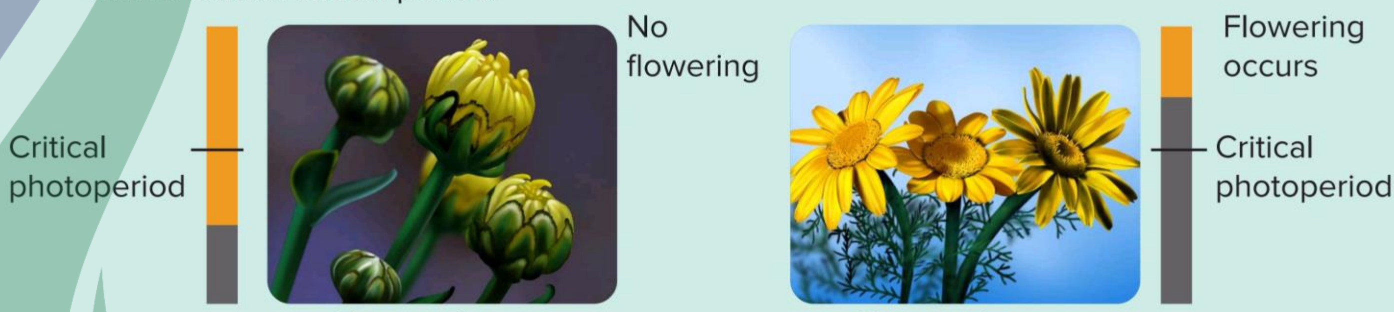


Critical photoperiod

- It is the definite period of light exposure, above or below which a plant does not flower.
- This critical photoperiod is different for different plants.

Photoperiodism in *Chrysanthemum*

- In *Chrysanthemum*, flowering occurs only if the length of the day or the photoperiod is shorter than a certain critical period.



Chrysanthemum *Chrysanthemum*

- In the given day-night graph, the length of the day exceeds the critical photoperiod.
- Hence, under these conditions, the flower does not bloom.

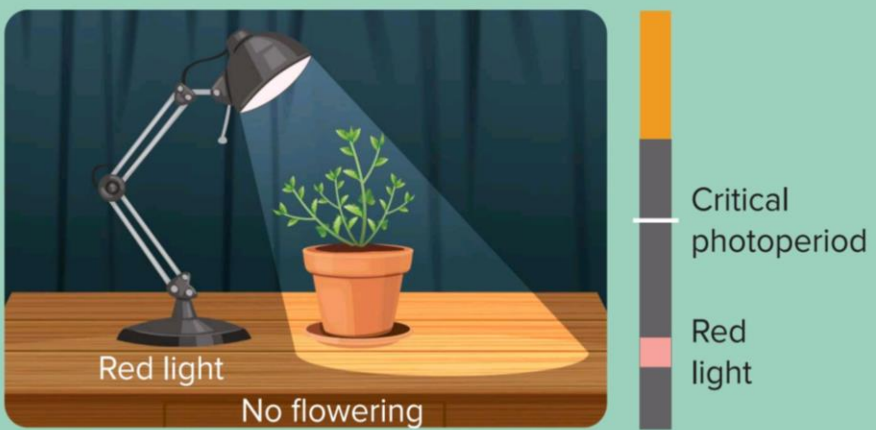
- In the given day-night graph, the length of the day is less than the critical photoperiod.
- When the duration of light reduces below the critical period, the plant starts to bloom.

→ It is important to remember that flowering response is initiated only if this condition is met for several days, weeks, or even months. The duration varies from species to species.

Photoperiodic perception

- Plants like *Chrysanthemum* can be take as an example to study this.
- The dark period is interrupted by light.
  - → If a flash of red light, which has a wavelength of 660 nm, is given to the plant, then the plant does not bloom.
  - → This condition persists even if the light period is below the critical photoperiod.
  - → This is known as the **light break reaction**.

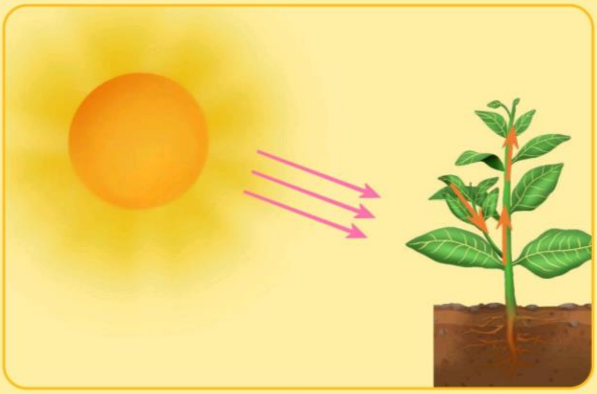
- Effect of interruption of dark period: Light break reaction



- However, this condition can be reversed.
- After being exposed to red light, if the plant is exposed to far-red light, which has a wavelength of approximately 730 nm, then the plant successfully blooms.

- Reversing the Light break reaction

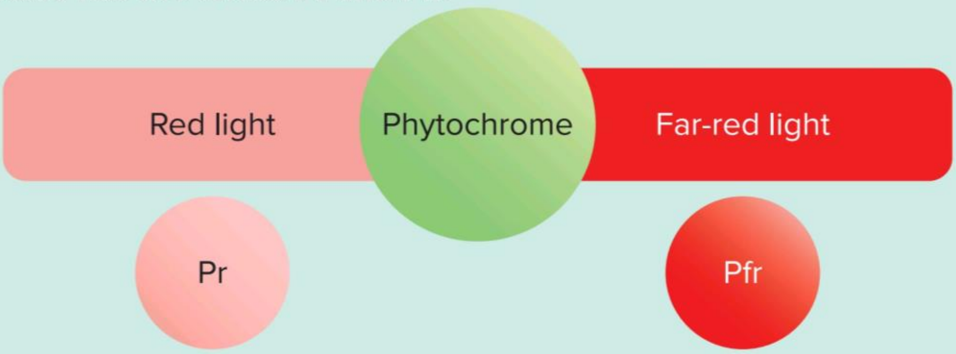
- **Leaves** are the sites of **perception of photoperiod**.



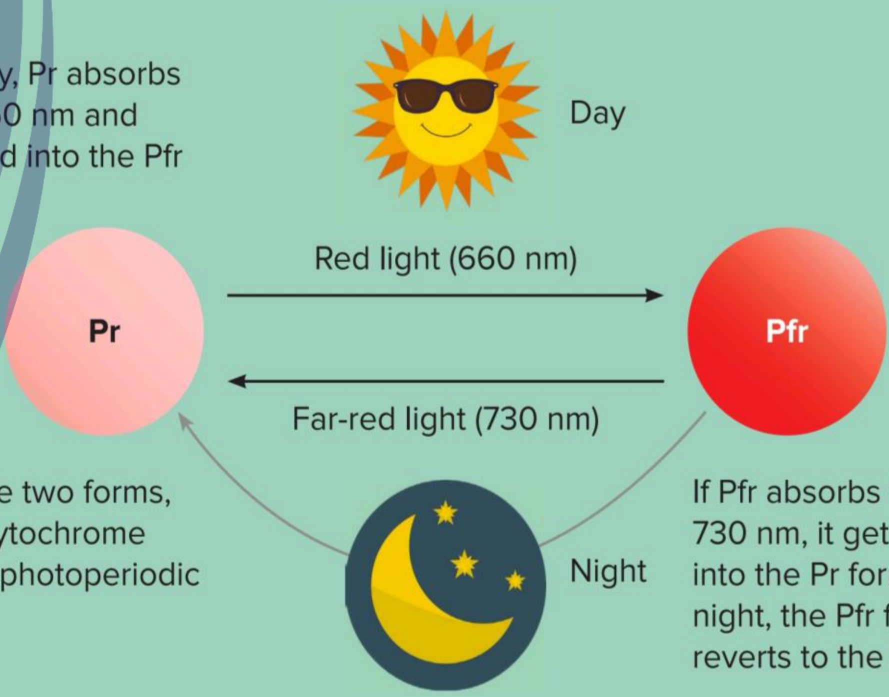
- The hormones and molecules responsible for the photoperiodic response migrate from leaves to shoot apices to induce flowering only when the plants are exposed to the necessary inductive photoperiod.

Phytochrome

- The photoperiodic response is mediated by a molecule that can detect red and far-red light.
- Phytochrome is a **plant pigment** that can detect red and far-red light. It **regulates** the **photoperiodic response**.
- The phytochrome has two forms: **Pr and Pfr**.



During the day, Pr absorbs red light at 660 nm and gets converted into the Pfr form.



Alternating the two forms, Pr and Pfr, phytochrome regulates the photoperiodic response.

If Pfr absorbs far-red light at 730 nm, it gets converted into the Pr form. During the night, the Pfr form slowly reverts to the Pr form.

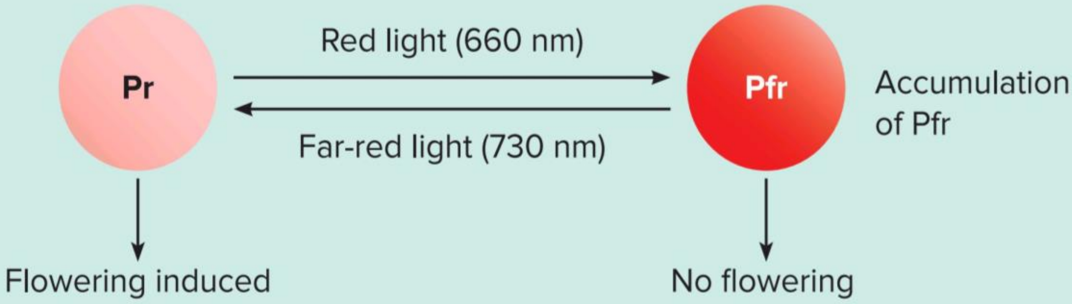
Types of plants based on photoperiod

Short-day

- They flower when the photoperiod or day length is below the critical period.

Chrysanthemum

- They are also known as **long-night plants**.
- In short-day plants, flowering is inhibited by the accumulation of Pfr.
- However, during dark, the slow conversion of Pfr into Pr induces flowering in short-day plants.



- Examples:

Xanthium

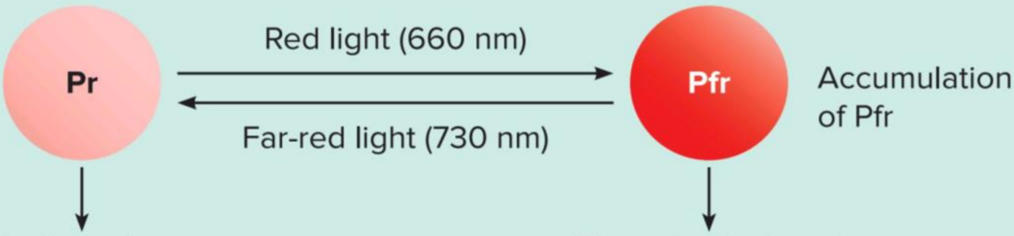
Strawberry

Long-day

- These plants flower when they receive long photoperiods or light hours that are above the critical length.
- They are also known as **short-night plants**.

Wheat

- In long-day plants, flowering is initiated by the accumulation of Pfr.
- However, during dark, the slow conversion of Pfr into Pr inhibits flowering in long-day plants.



- Examples:

Oats

Barley

Day-neutral

- There is **no correlation between light or dark periods** and flowering.
- Plants blossom throughout the year.
- Examples:

Tomato

Cucumber

Vernalisation

- It is the phenomenon due to which flowering depends either quantitatively or qualitatively on the exposure to a **low temperature**.
- It **promotes vegetative growth**.
  - ➔ It ensures **proper development** of leaves, stems, and the vascular system.
  - ➔ It **prevents premature development** of reproductive parts.

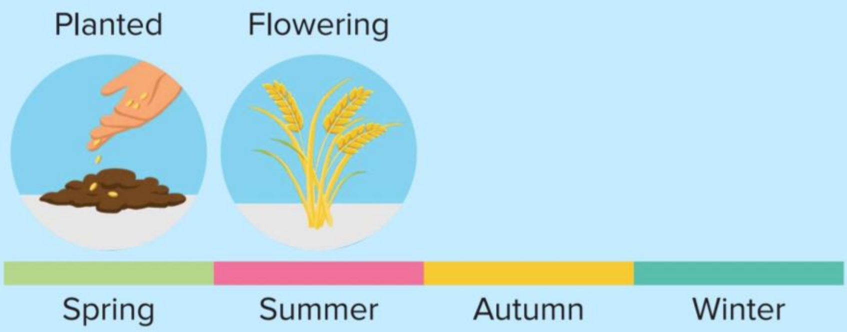
Types of plants

Annual

- Annual plants are those which germinate, grow, and bloom in **one year**.
- Some annual plants like wheat, barley, and rye have two varieties:

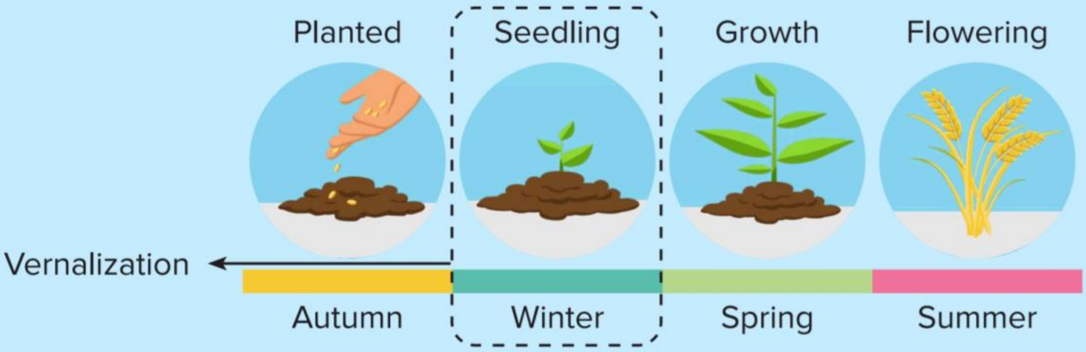
Spring varieties

- Planted in spring
- Grow over spring and some parts of summer
- Can be harvested in mid- summer
- Do not require any exposure to cold conditions to flower



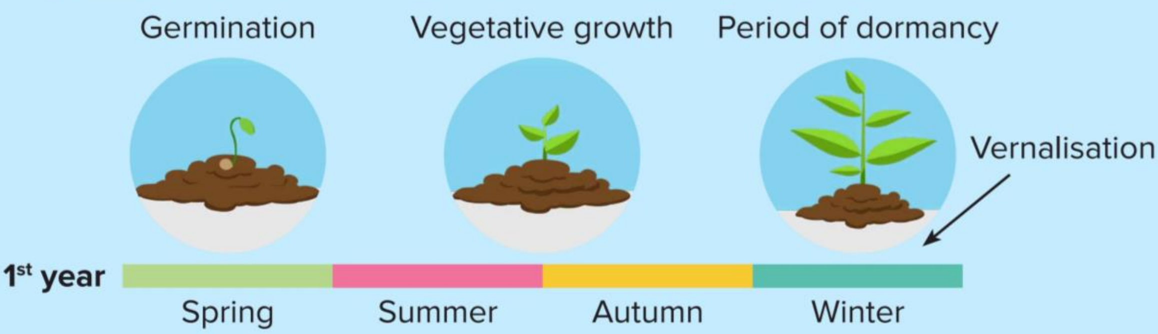
Winter varieties

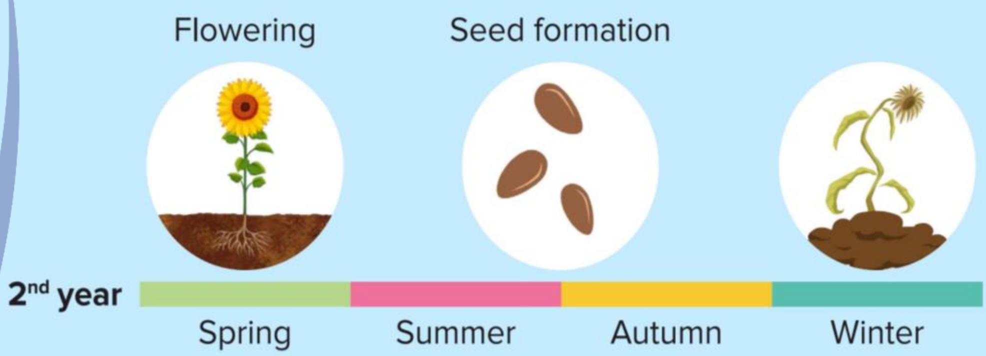
- Planted in autumn
- Grow into small seedlings in winter and continue their growth in spring
- Finally in mid-summer, they flower and produce grain and can be harvested
- Need to go through the winter cold to produce flowers



Biennials

- These are monocarpic plants that grow and flower over **two years**
- Examples: Sugarbeet and cabbage
- Bi: Two; Annus: Years
- Biennials are sown in spring
- They germinate in spring, undergo vegetative growth in summer and once they reach winter, they enter a period of dormancy
- In the second year, the plants flower in spring, form seeds in summer, and die in winter
- The key is the exposure to cold in winter, and this shows vernalisation in biennials





- Subjecting the growth of a biennial plant to a cold treatment stimulates a subsequent photoperiodic flowering response.
- This speeds up the process of flowering in biennials.

Vernalisation in biennials

Application of cold conditions

↓

Sugarbeet

Cabbage

↓

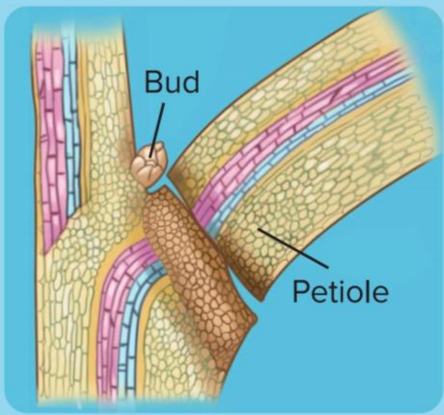
Early flowering

Perennials

- These are the plants that live for **more than two years**.
- The winter varieties show vernalisation.

Abscission

- Abscission is the process by which the **senescent part** of the plant is **separated from the plant**.
- Senescence occurs at a region known as the **abscission zone**.
- In leaves, the abscission zone is present at the base of the petiole.
- Importance of abscission:
  - Removal of the dead organs
  - Prevention of contraction of infection



Factors affecting abscission

Auxin	Ethylene	Abscisic acid
Promotes abscission of old leaves and fruits	Promotes abscission of leaves and flowers	Promotes abscission

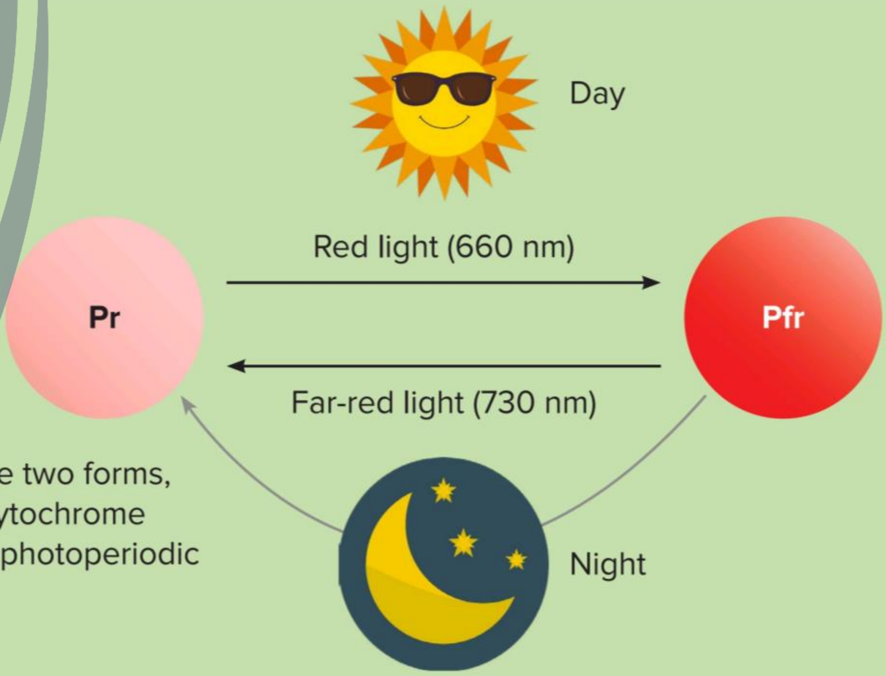
Summary Sheet

Photoperiodism

Photoperiodism: It is the response of plants to the relative length of day and night.

Critical photoperiod: It is the definite period of light exposure, above or below which a plant does not flower.

Phytochrome: It is a plant pigment that can detect red and far-red light. It regulates the photoperiodic response. The phytochrome has two forms: Pr and Pfr.



Alternating the two forms, Pr and Pfr, phytochrome regulates the photoperiodic response.

Types of plants based on photoperiod

Short-day

- Require a lower photoperiod than the critical photoperiod for flowering
- Also known long-night plants
- Examples: *Xanthium*, strawberry

Long-day

- Require a higher photoperiod than the critical photoperiod for flowering
- Also known as short-night plants
- Examples: Oats, barley

Day-neutral

- No correlation between light or dark periods and flowering
- Examples: Tomato, cucumber, sunflower

Vernalisation

Vernalisation: It is a phenomenon due to which flowering depends either quantitatively or qualitatively on the exposure to a low temperature.

Plant types

Annual
Plants that germinate, grow, and bloom in one year

- **Spring varieties**: Do not require any exposure to cold conditions to flower
- **Winter varieties**: They need to go through the winter cold to produce flowers in the next summer (vernalisation).

Biennials
Monocarpic plants that grow and flower over two years

Perennials
Plants that live for more than two years

Senescence and Abscission

Senescence	Abscission
Senescence is the deterioration of plants or plant organs that leads to the loss of functional activity.	Abscission is the process by which the senescent part of the plant is separated from the plant.
Factors affecting senescence: • Gibberellins: Delay senescence • Cytokinins: Delay leaf senescence • Ethylene: Promotes senescence	Factors affecting abscission: • Auxin: Promotes abscission of old leaves and fruits • Ethylene: Promotes abscission of leaves and flowers • Abscisic acid: Promotes abscission