Unit V: Plant Physiology (Functional Organisation)

Chapter 15

Plant Growth and Development

Learning Objectives

The learner will be able to,

- *Define growth.*
- *List out and differentiate the phases of growth.*
- *Understand the ways of measuring growth.*
- *Explain the structure, precursor, bioassay and physiological effects of plant growth regulators.*

Chapter Outline

15.1 Characteristics of growth
15.2 Plant growth regulators
15.3 Photoperiodism
15.4 Vernalization
15.5 Seed germination and dormancy
15.6 Senescence

The Banyan tree continues to grow for thousands of years and some others particularly annual plants cease growth within a season or within a year. Can you understand the reasons? How does a zygote give rise to an embryo and an embryo to a seedling? How does a new plant structure arise from the pre-existing structure? Growth is defined as an irreversible permanent increase in size, shape, number,volume and dry weight. Plant growth occurs by cell division, cell enlargement, differentiation and maturation.

DO YOU KNOW?

Bamboos are evergreen grasses and certain species of it can grow at the rate of growth 91 cm per day. The Saguaro Cactus is a tree like cactus and is a slow growing plant. The rate of growth is one inch in the first ten years and it does not begin to flower until it is about 60 years old. It's lifespan exceeds 150 years and takes 75–100 years to grow a side arm.

15.1 Characteristics of Growth

- Growth increases in protoplasm at cellular level.
- Stem and roots are indeterminate in growth due to continuous cell division and is called **open form of growth**.

DO YOU KNOW?

Growth is measurable, it is amazing to know that one single maize root apical meristem can give rise to more than 17,500 new cells per hour and cells in a watermelon may increase in size upto 3,50,000 times.

- The primary growth of the plant is due to the activity of apical meristem where, new cells are added to root and shoot apex causing linear growth of plant body.
- The secondary vascular cambium and cork cambium add new cells to cause increase in girth.
- Leaves, flowers and fruits are limited in growth or of determinate or **closed form growth.**
- Monocarpic annual plants produce flowers only once during lifetime and dies. Example: Paddy and Bean
- Monocarpic perennials produce flowers only once during life time but the plants survive for many years. Example: Bamboo.
- Polycarpic perennials produce flowers every year during life time. Example: Coconut.

15.1.1 Indication of growth

Growth in plants can be measured in terms of,

i. Increase in length or girth (roots and stems)

ii. Increase in fresh or dry weight

iii. Increase in area or volume (fruits and leaves)

iv. Increase in number of cells produced.

15.1.2 Phases of growth

There are three phases of growth,

1. Formative phase
2. Elongation phase
3. Maturation phase

1. Formative phase: Growth in this phase occurs in meristematic cells of shoot and root tips. These cells are small in size, have dense protoplasm, large nucleus and small vacuoles. Cells divide continuously by mitotic cell division. Some cells retain capability of cell division while other cells enter the next phase of growth (Figure 15.1).

2. Elongation Phase: Newly formed daughter cells are pushed out of the meristematic zone and increases the volume. It requires auxin and food supply, deposition of new cell wall materials (intussusception), addition of protoplasm and development of central vacuole take place.

3. Maturation Phase: During this stage cells attain mature form and size. Thickening and differentiation takes place. After differentiation, the cells do not grow further.

Activity

Demonstration of phases of growth

To demonstrate and study the phases of growth, germinate a few seeds of bean on a circular filter paper soaked with water in a petridish. After two days of growth, select a few seedlings with straight radical of 2 to 3 cm length. Dry the surface of radical with a blotting paper and mark the radical from tip to base with at least 2 mm gap using water proof ink. Replace the seedlings in filter paper and observe further growth.

Figure 15.1: Phases of growth in root

15.1.3 Kinetics of growth

It is an analysis of the motion of cells or expansion.

1. Stages in Growth rate

The total period from initial to the final stage of growth is called the **grand period of growth.** The total growth is plotted against time and 'S' shaped sigmoid curve (Grand period curve) is obtained. It consists of four phases (Figure 15.2). They are:

i. Lag phase
ii. Log phase
iii. Decelerating phase
iv. Maturation phase

i. Lag phase

In this phase new cells are formed from pre-existing cells slowly. It is found in the tip of the stem, root and branches. It is the initial stage of growth. In other words, growth starts from this period (Figure 15.2).

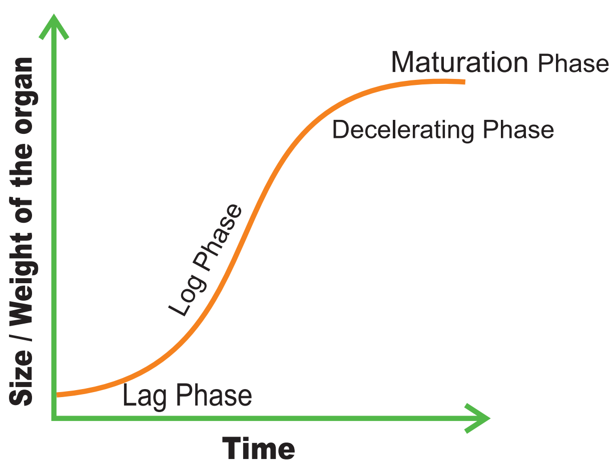


Figure 15.2: Stages in growth rate

ii. Log phase or exponential growth

Here, the newly formed cell increases in size rapidly by deposition of cell wall material. Growth rate is maximum and reaches top because of cell division and physiological processes are quite fast. The volume of protoplasm also increases. It results in rapid growth and causes elongation of internode in the stem.

iii. Decelerating phase or Decline phase or slow growth phase

The rate of growth decreases and becomes limited owing to internal and external or both the factors because the metabolic process becomes slow.

iv. Steady state period or maturation phase

In this phase cell wall thickening due to new particle deposition on the inner surface of the cell wall takes place. The overall growth ceases and becomes constant. The growth rate becomes zero.

2. Types of growth rate

The increased growth per unit time is termed as growth rate. An organism or part of an organism can produce more cells through arithmetic growth or geometric growth or both.

i. Arithmetic Growth Rate

If the length of a plant organ is plotted against time, it shows a linear curve and this growth is called **arithmetic growth**.

- The rate of growth is constant and it increases in an arithmetic manner.

- Only one cell is allowed to divide between the two-resulting progeny cell.
- One continues to divide but the other undergoes cell cycle arrest and begins to develop, differentiate and mature.
- After each round of cell division, only a single cell remains capable of division and one new body cell forms.

For example, starting with a single cell after round 1 of cell division there is one dividing cell and one body cell. After round 2 there are two body cells, after round 3 there are three and so on (Figure 15.3).

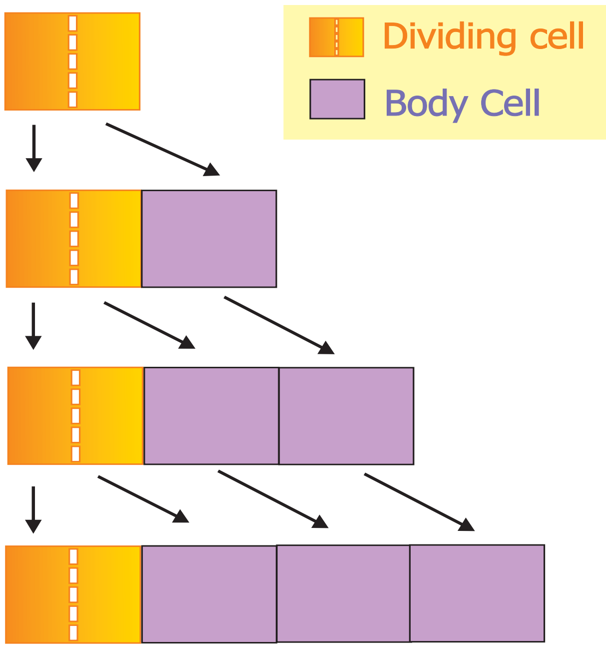


Figure 15.3: Arithmetic Growth Rate

The plants single dividing cell would undergo one million rounds of nuclear and cellular division. If each round requires one day, this type of arithmetic increase would require one million days or 2739.7 years. This arithmetic rate is capable of producing small number of cells present in very small parts of plants. For example the hair on many leaves and stems consists of just a single row of cells produced by the division of the basal cell, the cell at the bottom of the hair next to other epidermal cells. Hair may contain 5 to 10 cells by the division of the basal cell. So, all its cells could be produced in just five to ten days. In the figure 15.4, on plotting the hight of the plant against time a linear curve is obtained. Mathematically it is expressed as:

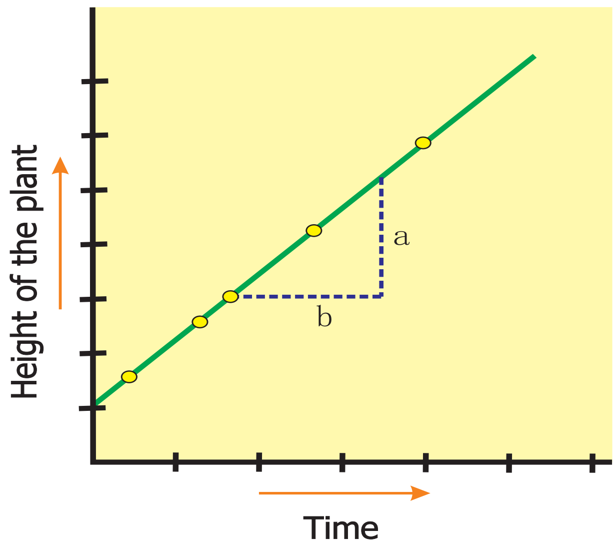


Figure 15.4: Constant Linear Growth

$L_t = L_o + rt$

L_t = length at time 't'

L_o = length at time zero

r = growth rate of elongation per unit

ii. Geometric growth rate:

This growth occurs in many higher plants and plant organs and is measured in size or weight. In plant growth, geometric cell division results if all cells of an organism or tissue are active mitotically. Example: Round three in the given figure 15.5, produces 8 cells as 2^3 = 8 and after round 20 there are 2^{20} = 1,048,576 cells.

The large plant or animal parts are produced this way. In fact, it is common in animals but rare in plants except when they are young and small. Exponential growth curve can be expressed as,

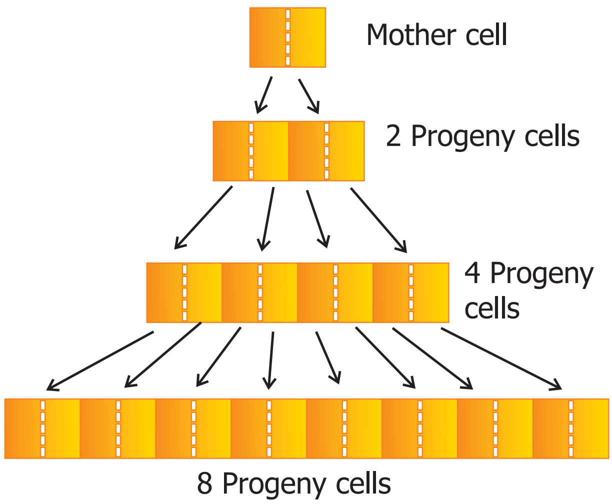


Figure 15.5: Geometric growth

$W_1 = W_0 e^{rt}$

W_1 = Final size (weight, height and number)

W_0 = Initial size at the beginning of the period

r = Growth rate

t = Time of growth

e = Base of the natural logarithms

Here 'r' is the relative growth rate and also a measure of the ability of the plant to produce new plant material, referred to as efficiency index. Hence, the final size of W_1 depends on the initial size W_0.

iii. Arithmetic and Geometric Growth of Embryo

Plants often grow by a combination of arithmetic and geometric growth patterns. A young embryonic plant grows geometrically and cell division becomes restricted to certain cells at the tips of roots and shoots. After this point, growth is of the slower arithmetic type, but some of the new cells that are produced can develop into their mature condition and begin carrying out specialized types of metabolism (Figure 15. 6). Plants are thus a mixture of older, mature cells and young, dividing cells.

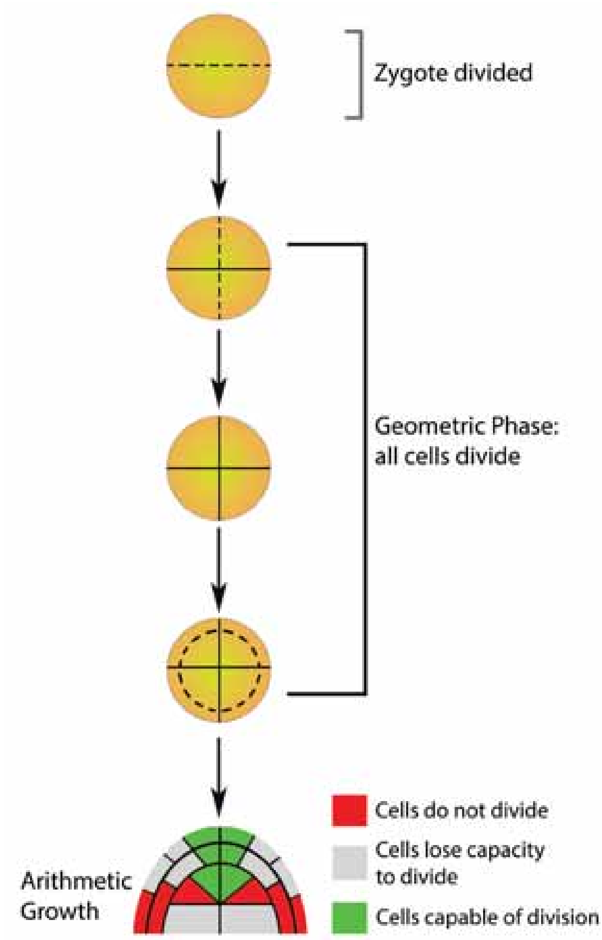


Figure 15.6: Arithmetic and geometric growth of embryo

Quantitative comparisons between the growth of living system can also be made in two ways and is explained in the table 1.

In figure 15.7, two leaves A and B are drawn at a particular time. Then $A^1$and B^1 are drawn after a given time. A and B = Area of leaves at a particular time. A^1 and B^1 = Area of leaves after a given time. (A^1-A) and (B^1-B) represents an absolute increase in area in the given time. Leaf A

Table 1: Comparison between absolute and relative growth rates

Absolute growth rate	Relative growth rate
Increase in total growth of two organs measured and compared per unit time is called absolute growth rate.	The growth of the given system per unit time expressed per unit initial parameter is called relative growth rate.

increases from 5 cm^2 to 10 cm^2; 5 cm^2 in a given time. Leaf B increases from 50 cm^2 to 55 cm^2 ; 5 cm^2 in a given time. Hence, both leaves A and B increase their area by 5 cm^2 in a given time. This is absolute growth. Relative growth is faster in leaf A because of initial small size. It decreases with time (Figure 15.7).

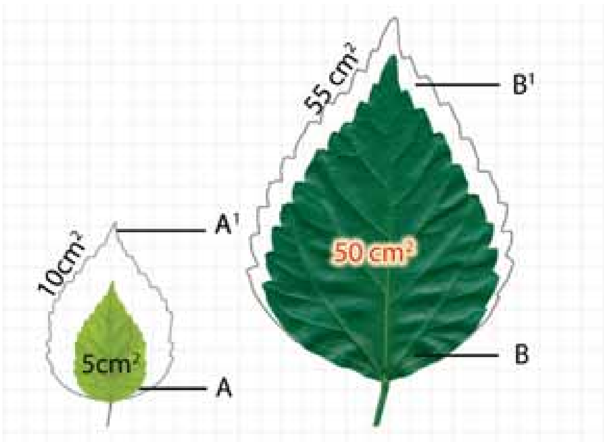


Figure 15.7: Diagrammatic comparision of absolute and relative growth rates

3.Conditions of growth

Plant growth is influenced by a variety of external and internal factors. A brief account of these factors is given below:

I. External Factors

a. Water

Water is essential for cell enlargement as well as growth in the size of the cell. Turgidity of cells helps in growth extension. Water provides the medium for enzymatic activities needed for growth.

b. Nutrition

Nutrition plays an important role in the formation of protoplasm. Macro and micro elements are very important as sources of energy. For example, carbon and oxygen in carbon-di-oxide and hydrogen in water are assimilated in photosynthesis.

c. Temperature

Temperature plays a significant role in the growth of the plant. Proper growth of a plant occurs at a about 28° C to 30° C temperature and above 45° C will damage the protoplasm and hinders the growth.

d. Oxygen

Oxygen has a vital role in the growth of the plant. It helps in releasing metabolic energy essential for growth activities. It is necessary for respiration.

e. Light

Light has its own contribution in the growth of the plant. Light is important for growth and photosynthesis. Light stimulates healthy growth. Absence of light may lead to yellowish in colour. This is called **etiolation**.

II. Internal Factors

a. Genes are intracellular factors for growth.
b. Phytohormones are intracellular factors for growth. Example: auxin, gibberellin, cytokinin.
c. C/N ratio.

The ratio of carbohydrates and nitrogenous compounds regulate the specific pattern of growth in plants. For example, if a plant contains more nitrogenous compounds as compared to carbohydrates it produces more protoplasm less mechanical tissues and vigorous vegetative growth. On the other hand, less nitrogenous compounds and more carbohydrates favour the synthesis of more wall material, less protoplasm, and more mechanical tissues.

4. Measurement of growth

Activity

Measurement of growth by direct method.

Step 1: Take ordinary scale.

Step 2: Measure ground stem up to the growing point of the plant.

Step 3: Use Indian ink and mark at regular intervals to measure the length of root, stem, and girth of the trunk.

5. Sequence of developmental process in a plant cell

Development is a term that includes all the changes that an organism goes through during life cyle from germination of a seed to senescence. Diagrammatic representation of the sequence of processes which constitute the development of a cell of a higher plant is given in the figure. It is also applicable to tissues/organ.

Experiment: 1. Arc auxanometer:

The increase in the length of the stem tip can easily be measured by an arc auxanometer which consists of a small pulley to the axis of which is attached a long pointer sliding over a graduated arc. A thread one end of which is tied to the stem tip and another end to a weight passes over the pulley tightly. As soon as the stem tip increases in length, the pulley moves and the pointer slide over the graduated arc (Figure 15.8). The reading is taken. The actual increase in the length of the stem is then calculated by knowing the length of the pointer and the radius of the pulley. If the radius of the pulley is 4 inches and the length of pointer 20 inches the actual growth is measured as follows:

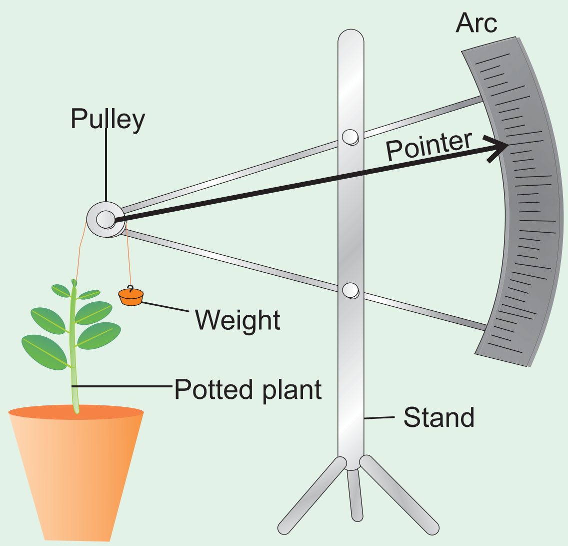


Figure 15.8: Arc auxanometer

$$\text{Actual growth in length} = \frac{\text{Distance travelled by the pointer} \times \text{radius of the pulley}}{\text{Length of the pointer}}$$

$$\text{For example, actual growth in length} = \frac{10 \times 4 \text{ inches}}{20 \text{ inches}}$$

$$= 2 \text{ inches}$$

1. Differentiation

The process of maturation of meristematic cells to specific types of cells performing specific functions is called **differentiation**.

2. Dedifferentiation

The living differentiated cells which had lost capacity to divide, regain the capacity to divide under certain conditions. Hence, dedifferentiation is the regaining of the ability of cell division by the differentiated cells. Example: Interfascicular cambium and Vascular cambium.

3. Redifferentiation

Differentiated cells, after multiplication again lose the ability to divide and mature to perform specific functions. This is called **redifferentiation** (Figure 15.9). Example: Secondary xylem and Secondary phloem.

4. Plasticity

Plants follow different pathways in response to environment or phases of life to form different kinds of structures.

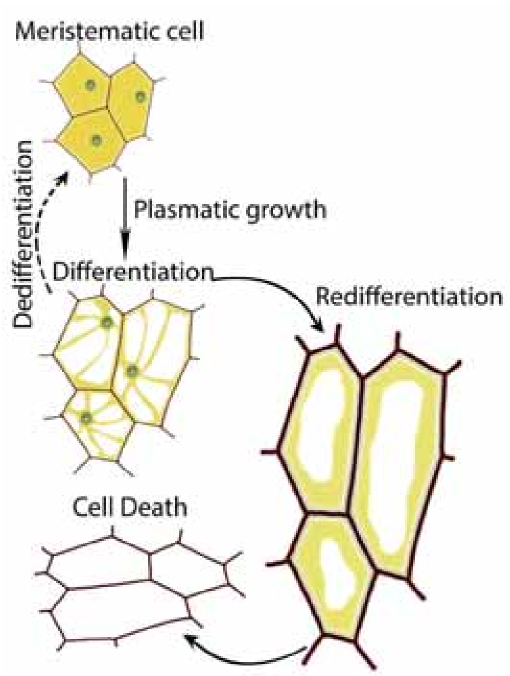


Figure 15.9: Sequences of developmental process in a plant cell

This ability is called **plasticity**. Example: Heterophylly in cotton and coriander. In such plants, the leaves of the juvenile plant are different in shape from those in mature plants. On the other hand, the difference in shapes of leaves produced in air and those produced in water in buttercup also represent the heterophyllous development due to the environment. This phenomenon of heterophylly is an example of plasticity.

15.2 Plant Growth Regulators

CRK9N8

Plant Growth Regulators (chemical messenger) are defined as organic substances which are synthesized in minute quantities in one part of the plant body and transported to another part where they influence specific physiological processes. Five major groups of hormones *viz.*, auxins, gibberellins, cytokinins, ethylene and abscisic acid are presently known to coordinate and regulate growth and development in plants. The term **phytohormones** is implied to those chemical substances which are synthesized by plants and thus, naturally occurring. On the other hand, there are several manufactured chemicals which often resemble the hormones in physiological action and even in molecular structure. Recently, another two groups, the brassinosteroids and polyamines were also known to behave like hormones.

1. Plant growth regulators – classification

Plant Growth Regulators are classified as natural and synthetic based on their

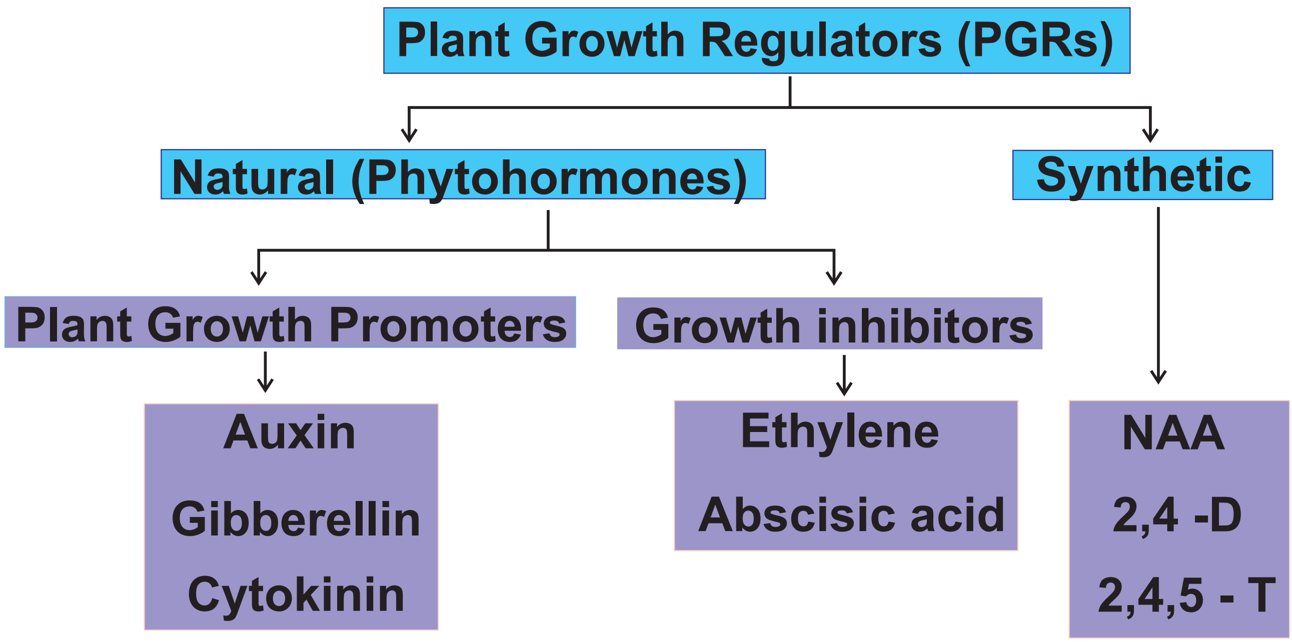


Figure 15.10: Classification of Plant Growth Regulators

source and a detailed flow diagram is given in Figure 15.10.

2. Characteristics of phytohormones

i. Usually produced in tips of roots, stems and leaves.
ii. Transfer of hormones from one place to another takes part through conductive systems.
iii. They are required in trace quantities.
iv. All hormones are organic in nature.
v. There are no specialized cells or organs for their secretion.
vi. They are capable of influencing physiological activities leading to promotion, inhibition and modification of growth.

3. Synergistic and Antagonistic effects

i. **Synergistic effects**: The effect of one or more substance in such a way that both promote each others activity. Example: Activity of auxin and gibberellins or cytokinins.
ii. **Antagonistic effects**: The effect of two substances in such a way that they have opposite effects on the same process. One accelerates and other inhibits. Example: ABA and gibberellins during seed or bud dormancy. ABA induces dormancy and gibberellins break it.

15.2.1 Auxins

1. Discovery

During 1880, **Charles Darwin** noted the unilateral growth and curvature of Canary grass (*Phalaris canariensis*) coleoptile to light. The term auxin (*Greek*: Auxin – to Grow) was first used by **F. W. Went** in 1926 using Oats (*Avena*) coleoptile and isolated the auxin. F. W. Went in 1928 collected auxin in agar jelly. **Kogl** and **Haugen Smith** (1931) isolated Auxin from human urine, and called it as **Auxin A**. Later on in 1934, similar active substances was isolated from corn grain oil and was named as **Auxin B**. Kogl *et al.*, (1934) found heteroauxin in the plant and chemically called it as **Indole Acetic Acid** (IAA)

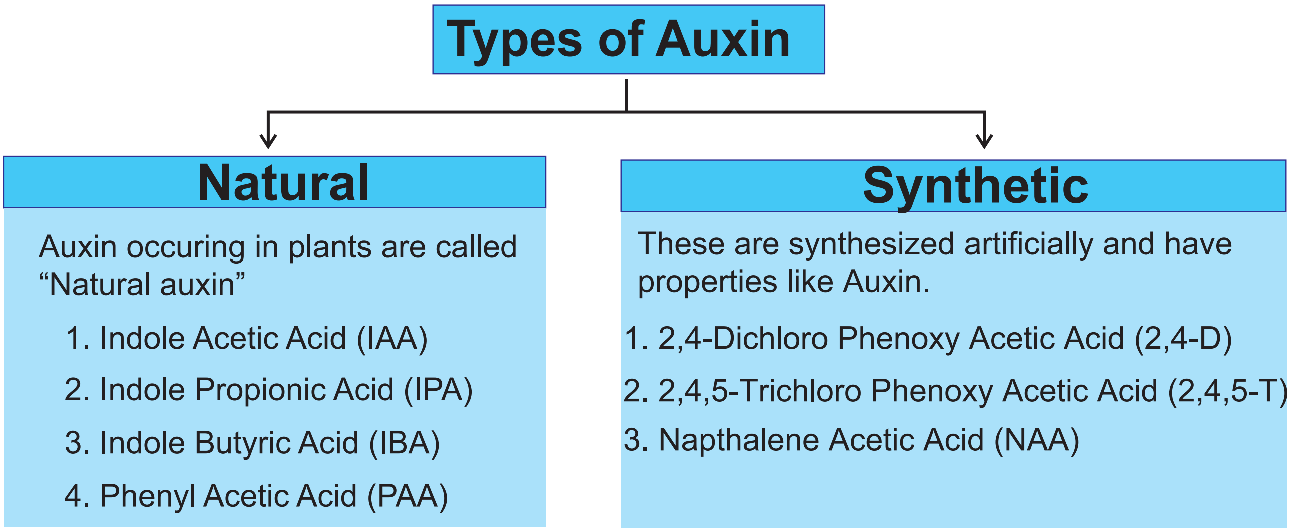


Figure 15.11: Classification of Auxins

2. Occurrence

Auxin is generally produced by the growing tips of the stem and root, from where they migrate to the region of the action.

3. Types of Auxin

Auxins are divided into two categories Natural auxins and Synthetic auxins (Figure 15.11).

> **Anti-auxins**
>
> Anti-auxin compounds when applied to the plant inhibit the effect of auxin. Example: 2, 4, 5-Tri Iodine Benzoic Acid (TIBA) and Napthylpthalamine.

4. Free auxin

They move out of tissues as they are easily diffusible. Example: IAA.

5. Bound Auxin

They are not diffusible. Example: IAA-Aspartic acid

6. Precursor

The amino acid Tryptophan is the precursor of IAA and zinc is required for its synthesis.

7. Chemical structure

Auxin has similar chemical structure of IAA.

8. Transport in Plants

Auxin is polar in transport. It includes basipetal and acropetal transport. Basipetal means transport through phloem from shoot to root and acropetal means transport through xylem from root to shoot.

9. Bioassay (Avena Curvature Test / Went Experiment)

Bioassay means testing of substances for their activity in causing a growth response in a living plant or its part.

The procedure involves the following steps:

When the *Avena* seedlings have attained a height of 15 to 30 mm, about 1mm of the coleoptile tip is removed. This apical part is the source of natural auxin. The tip is now placed on agar blocks for few hours. During this period, the auxin diffuses out of these tips into the agar. The auxin containing agar block is now

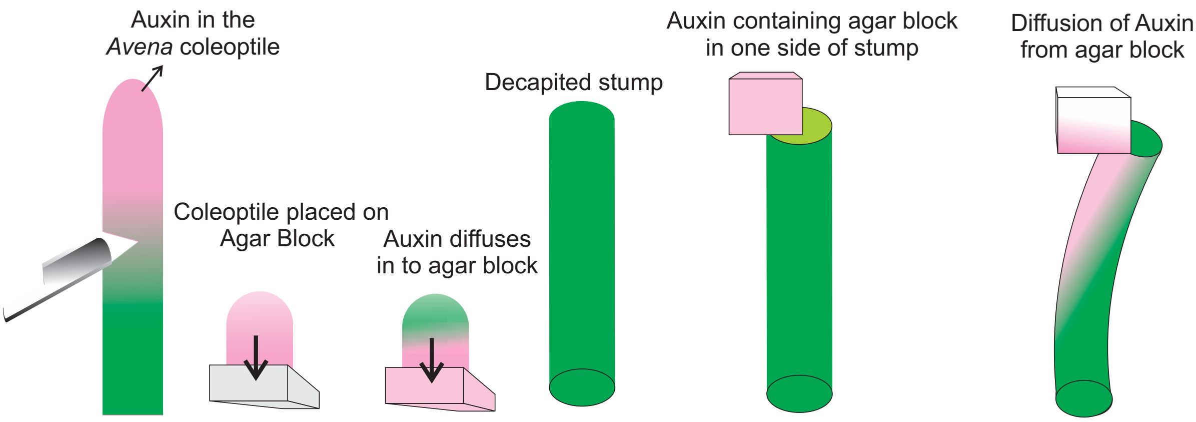


Figure 15.12: *Avena* Curvature Test

placed on one side of the decapitated stump of *Avena* coleoptile. The auxin from the agar blocks diffuses down through coleoptile along the side to which the auxin agar block is placed. An agar block without auxin is placed on another decapitated coleoptile. Within an hour, the coleoptiles with auxin agar block bends on the opposite side where the agar block is placed. This curvature can be measured (Figure 15.12).

10. Physiological Effects

- They promote cell elongation in stem and coleoptile.
- At higher concentrations auxins inhibit the elongation of roots but induce more lateral roots. Promotes growth of root only at extremely low concentrations.
- Suppression of growth in lateral bud by apical bud due to auxin produced by apical bud is termed as **apical dominance**.
- Auxin prevents abscission.
- It is responsible for initiation and promotion of cell division in cambium, which is responsible for the secondary growth and tumor. This property of induction of cell division has been exploited for tissue culture techniques and for the formation of callus.
- Auxin stimulates respiration.
- Auxin induces vascular differentiation.

Agent Orange

Mixture of two phenoxy herbicides 2,4-D and 2,4,5-T is given the name 'Agent orange' which was used by USA in Vietnam war for defoliation of forest (chemical warfare).

In botanical gardens and tea gardens, gardeners trim the plants regularly so that they remain bushy. Does this practice have any scientific explanation?

Yes, trimming of plants removes apical buds and hence apical dominance. The lateral buds sprout and make the plants bushy.

11. Agricultural role

- It is used to eradicate weeds. Example: 2,4-D and 2,4,5-T.
- Synthetic auxins are used in the formation of seedless fruits (Parthenocarpic fruit).
- It is used to break the dormancy in seeds.
- Induce flowering in Pineapple by NAA & 2,4-D.
- Increase the number of female flowers and fruits in cucurbits.

15.2.2 Gibberellins

1. Discovery

The effect of gibberellins had been known in Japan since early 1800 where certain rice plants were found to suffer from '**Bakanae**' or foolish seedling disease. This disease was found by **Kurosawa** (1926) to be caused by a fungus *Gibberella fujikuroi*. The active substance was separated from fungus and named as gibberellin by **Yabuta** (1935). These are more than 100 gibberellins reported from both fungi and higher plants. They are noted as GA_1, GA_2, GA_3 and so on. GA_3 is the first discovered gibberellin. In 1938, **Yabuta** and **Sumiki** isolated gibberellin in crystalline form. In1955, **Brain** *et al.,* gave the name **gibberellic acid**. In 1961, Cross *et al.,* established its structure.

2. Occurrence

The major site of gibberellin production in plants is parts like embryo, roots and young leaves near the tip. Immature seeds are rich in gibberellins.

3. Precursors

The gibberellins are chemically related to terpenoids (natural rubber, carotenoids and steroids) formed by 5-C precursor, an Isoprenoid unit called Iso Pentenyl Pyrophosphate (IPP) through a number of intermediates. The primary precursor is acetate.

4. Chemical structure

All gibberellins have gibbane ring structure.

5. Transport in plants

The transport of gibberellins in plants is non-polar. Gibberellins are translocated through phloem and also occur in xylem due to lateral movement between vascular bundles.

6. Bioassay (Dwarf Pea assay)

Seeds of dwarf pea are allowed to germinate till the formation of the coleoptile. GA solution is applied to some seedlings. Others are kept under control. Epicotyle length is measured and as such, GA stimulating epicotyle growth can be seen.

7. Physiological Effects

- It produces extraordinary elongation of stem caused by cell division and cell elongation.
- Rosette plants (genetic dwarfism) plants exhibit excessive internodal growth when they are treated with gibberellins. This sudden elongation of stem followed by flowering is called **bolting** (Figure 15.13).
- Gibberellin breaks dormancy in potato tubers.
- Many biennials usually flower during second year of their growth. For flowering to take place, these plants should be exposed to cold season. Such plants could be made to flower without

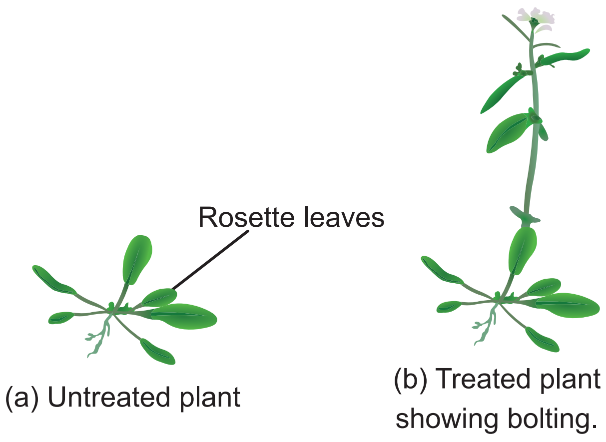


Figure 15.13: Bolting

exposure to cold season in the first year itself, when they are treated with gibberellins.

8. Agricultural role

- Formation of seedless fruits without fertilization is induced by gibberellins Example: Seedless tomato, apple and cucumber.
- It promotes the formation of male flowers in cucurbitaceae. It helps in crop improvement.
- Uniform bolting and increased uniform seed production.
- Improves number and size of fruits in grapes. It increase yield.
- Promotes elongation of inter-node in sugarcane without decreasing sugar content.
- Promotion of flowering in long day plants even under short day conditions.
- It stimulates the seed germination.

15.2.3 Cytokinins (*Cytos* – cell, *Kinesis* – division)

1. Discovery

The presence of cell division inducing substances in plants was first demonstrated by **Haberlandt** in 1913 in Coconut milk (liquid endosperm of coconut) which contains cell division inducing substances. In 1954, Skoog and Miller discovered that autoclaved DNA from herring sperm stimulated cell division in tobacco pith cells. They called this cell division inducing principle as kinetin (chemical structure: 6-Furfuryl Amino Acid). This does not occur in plants. In 1963, Lethan introduced the term cytokinin. In 1964, Lethan and Miller isolated and identified a new cytokinin called **Zeatin** from unripe grains of maize. The most widely occurring cytokinin in plants is Iso Pentenyl adenine (IPA).

2. Occurrence

Cytokinin is formed in root apex, shoot apex, buds and young fruits.

3. Precursor

Cytokinins are derivatives of the purine adenine.

4. Bioassay (Neem Cotyledon Assay)

Neem cotyledons are measured and placed in cytokinin solution as well as in ordinary water. Enlargement of cotyledons is an indication of cytokinin activity.

5. Transport in plants

The distribution of cytokinin in plants is not as wide as those of auxin and gibberellins but found mostly in roots. Cytokinins appear to be translocated through xylem.

6. Physiological effect

- Cytokinin promotes cell division in the presence of auxin (IAA).
- Induces cell enlargement associated with IAA and gibberellins

- Cytokinin can break the dormancy of certain light-sensitive seeds like tobacco and induces seed germination.
- Cytokinin promotes the growth of lateral bud in the presence of apical bud.
- Application of cytokinin delays the process of aging by nutrient mobilization. It is known as **Richmond Lang effect**.
- Cytokinin (i) increases rate protein synthesis (ii) induces the formation of inter-fascicular cambium (iii) overcomes apical dominance (iv) induces formation of new leaves, chloroplast and lateral shoots.
- Plants accumulate solutes very actively with the help of cytokinins.

15.2.4 Ethylene (Gaseous Phytohormone)

Almost all plant tissues produce ethylene gas in minute quantities.

1. Discovery

In 1924, **Denny** found that ethylene stimulates the ripening of lemons. In 1934, **R. Gane** found that ripe bananas contain abundant ethylene. In 1935, **Cocken** *et al.*, identified ethylene as a natural plant hormone.

2. Occurrence

Maximum synthesis occurs during climacteric ripening of fruits (*see* Box info) and tissues undergoing senescence. It is formed in almost all plant parts like roots, leaves, flowers, fruits and seeds.

3. Transport in plants

Ethylene can easily diffuse inside the plant through intercellular spaces.

4. Precursor

It is a derivative of amino acid methionine, linolenic acid and fumaric acid.

5. Bioassay (Gas Chromatography)

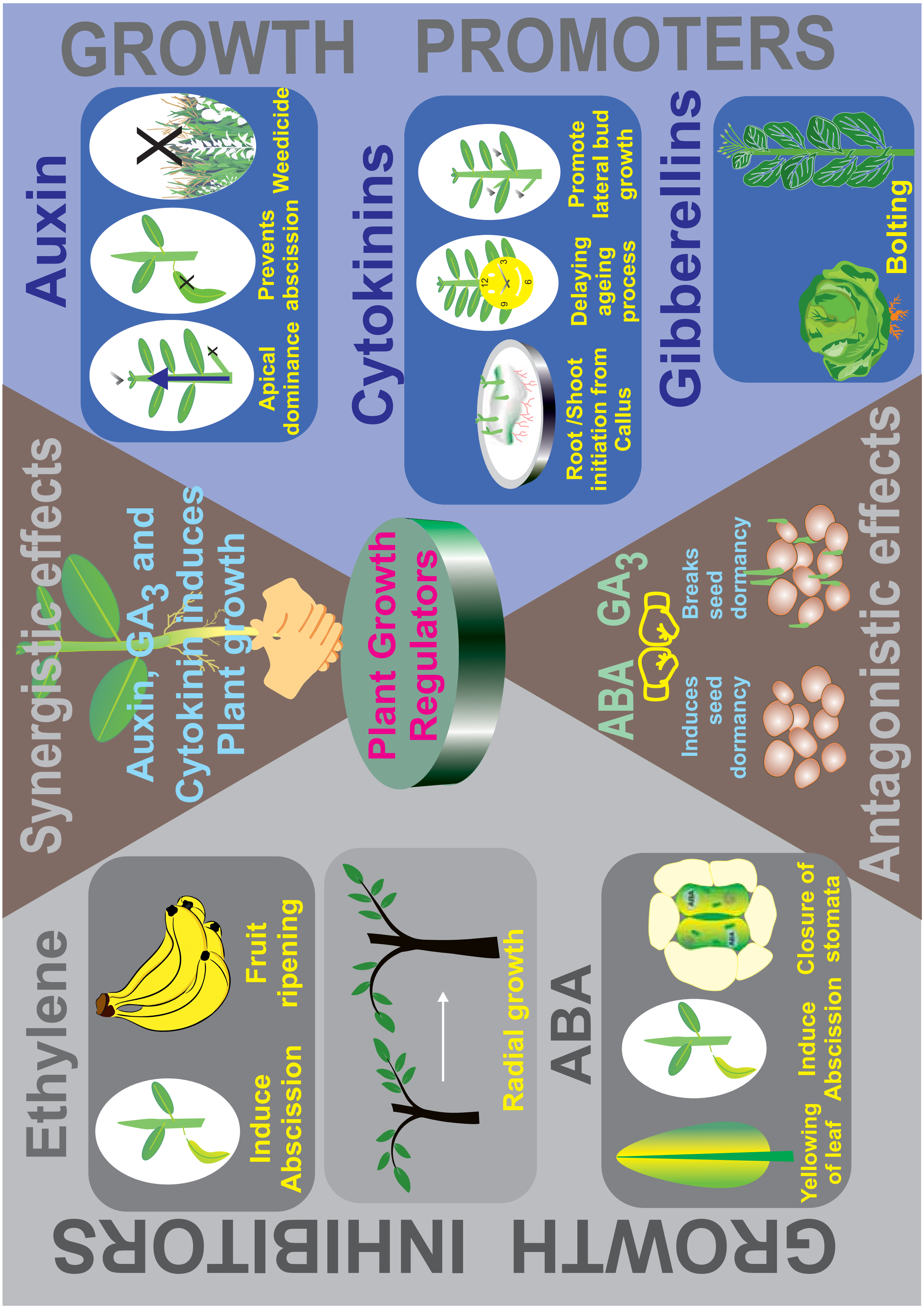
Ethylene can be measured by gas chromatography. This technique helps in the detection of exact amount of ethylene from different plant tissues like lemon and orange.

6. Physiological Effects

- Ethylene stimulates respiration and ripening in fruits.
- It stimulates radial growth in stem and root and inhibits linear growth.
- It breaks the dormancy of buds, seeds and storage organs.
- It stimulates formation of abscission zone in leaves, flowers and fruits. This makes the leaves to shed prematurely.
- Inhibition of stem elongation (shortening the internode).
- In low concentration, ethylene helps in root initiation.
- Growth of lateral roots and root hairs. This increases the absorption surface of the plant roots.
- The growth of fruits is stimulated by ethylene in some plants. It is more marked in climacteric fruits.
- Ethylene causes epinasty.

Agricultural role

- Ethylene normally reduces flowering in plants except in Pine apple and Mango.
- It increases the number of female flowers and decreases the number of male flowers.
- Ethylene spray in cucumber crop produces female flowers and increases the yield.


GROWTH PROMOTERS
Auxin
Apical dominance
Prevents abscission
Weedicide
Cytokinins
Root /Shoot initiation from Callus
Delaying ageing process
Promote lateral bud growth
Gibberellins
Bolting
Plant Growth Regulators
Synergistic effects
Auxin, GA_3 and Cytokinin induces Plant growth
Antagonistic effects
ABA GA_3
Induces seed dormancy
Breaks seed dormancy
Ethylene
Induce Abscission
Fruit ripening
Radial growth
ABA
Yellowing of leaf
Induce Abscission
Closure of stomata
GROWTH INHIBITORS

Climacteric fruits: In most of the plants, there is sharp rise in respiration rate near the end of the development of fruit, called climacteric rise. Such fruits are called climacteric fruits. The ripening on demand can be induced in these fruits by exposing them to normal air containing about 1 ppm of ethylene. A liquid called ethephon is being used in fruit ripening as it continuously releases ethylene.

Example: Tomato, Apples, Banana, Mango.

Non climacteric fruits: All fruits cannot be ripened by exposure to ethylene. Such fruits are called non-climacteric fruits and are insensitive to ethylene.

Example: Grapes, Watermelon, Orange.

15.2.5 Abscisic Acid (ABA) (Stress Phyto Hormone)

1. Discovery

In 1963, the hormone was first isolated by **Addicott *et al.*,** from young cotton bolls and named as **Abscission II**. Eagles and Wareing during 1963–64 isolated a dormancy inducing substance from leaves of *Betula* and called it as dormin. In 1965, it was found by Cornsforth *et al*., that both dormin and abscission are chemically same compounds and called **Abscisic Acid (ABA)**.

2. Occurrence

This hormone is found abundantly inside the chloroplast of green cells.

3. Precursors

The hormone is formed from mevalonic acid pathway or xanthophylls.

4. Transport in plants

Abscisic acid is transported to all parts of the plant through diffusion as well as through phloem and xylem.

5. Chemical structure

It has carotenoid structure.

6. Bioassay (Rice Coleoptile)

The inhibition of IAA induces straight growth of rice seedling coleoptiles.

7. Physiological effects

- It helps in reducing transpiration rate by closing stomata. It inhibits K^+ uptake by guard cells and promotes the leakage of malic acid. It results in closure of stomata.
- It spoils chlorophylls, proteins and nucleic acids of leaves making them yellow.
- Inhibition of cell division and cell elongation.
- ABA is a powerful growth inhibitor. It causes 50% inhibition of growth in Oat coleoptile.
- It induces bud and seed dormancy.
- It promotes the abscission of leaves, flowers and fruits by forming abscission layers.
- ABA plays an important role in plants during water stress and during drought conditions. It results in loss of turgor and closure of stomata.
- It has anti-auxin and anti-gibberellin property.
- Abscisic acid promotes senescence in leaves by causing loss of chlorophyll pigment decreasing the rate of

photosynthesis and changing the rate of proteins and nucleic acid synthesis.

8. Agricultural Role

- In *Cannabis sativa*, induces male flower formation on female plants.
- Induction of flowers in short day plants.
- It promotes sprouting in storage organs like Potato.
- ABA plays an important role in plants during water stress drought conditions.
- It inhibits the shoot growth and promotes growth of root system. This character protect the plants from water stress. Hence, ABA is called as **stress hormone.**

15.3 Photoperiodism

Trees take several years for initiation of flowering whereas an annual herb flowers within few months. Each plant requires a specific time period to complete their vegetative phase which will be followed by reproductive phase as per their internal control points through Biological Clock. The physiological mechanisms in relation to flowering are controlled by (i) light period (Photoperiodism) and (ii) temperature (Vernalization). The physiological change on flowering due to relative length of light and darkness (photoperiod) is called **Photoperiodism**. The term photoperiodism was coined by **Garner** and **Allard** (1920) when they observed this in 'Biloxi' variety of soybean (*Glycine max*) and 'Maryland mammoth' variety of tobacco (*Nicotiana tabacum*). The photoperiod required to induce flowering is called **critical day length**. Maryland mammoth (tobacco variety) requires 12 hours of light and cocklebur (*Xanthium pensylvanicum*) requires 15.05 hours of light for flowering.

1. Classification of plants based on Photoperiodism

Depending upon the photoperiodic responses plants are classified as given in Figure 15.14.

i. **Long day plants**: The plants that require long critical day length for flowering are called long day plants or short night plants. Example: Pea, Barley and Oats.

ii. **Short long day plants**: These are long day plants but should be exposed to short day lengths during early period of growth for flowering. Example: Wheat and Rye.

iii. **Short day plants**: The plants that require a short critical day length for flowering are called short day plants or long night plants. Example: Tobacco, Cocklebur, Soybean, Rice and *Chrysanthemum*.

iv. **Long short day plants**: These are actually short-day plants but they have to be exposed to long days during their early periods of growth for flowering.

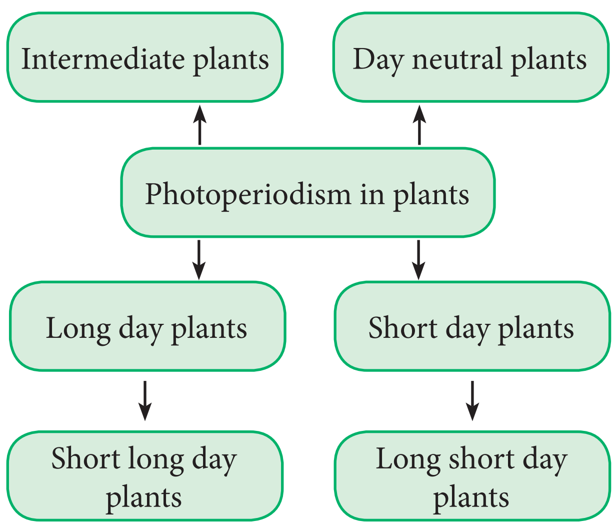


Figure: 15.14 Classification of Plants based on Photoperiodism

Example: Some species of *Bryophyllum* and Night jasmine.

v. **Intermediate day plants:** These require a photoperiod between long day and short day for flowering. Example: Sugarcane and *Coleus*.

vi. **Day neutral plants**: There are a number of plants which can flower in all possible photoperiods. They are also called **photo neutrals** or **indeterminate plants**. Example: Potato, *Rhododendron*, Tomato and Cotton.

2. Photoperiodic induction

An appropriate photoperiod in 24 hours' cycle constitutes one inductive cycle. Plants may require one or more inductive cycles for flowering. The phenomenon of conversion of leaf primordia into flower primordia under the influence of suitable inductive cycles is called **photoperiodic induction**. Example: *Xanthium* (SDP) – 1 inductive cycle and *Plantago* (LDP) – 25 inductive cycles.

3. Site of Photoinductive perception

Photoperiodic stimulus is perceived by the leaves. Floral hormone is synthesised in leaves and translocated to the apical tip to promote flowering. This can be explained by a simple experiment on Cocklebur (*Xanthium pensylvanicum*), a short day plant. Usually *Xanthium* will flower under short day conditions. If the plant is defoliated and kept under short day conditions it will not flower. Flowering will occur even when all the leaves are removed except one leaf. If a cocklebur plant is defoliated and kept under long day conditions, it will not flower. If one of its leaves is exposed to short day condition and rest are in long day condition, flowering will occur (Figure 15.15).

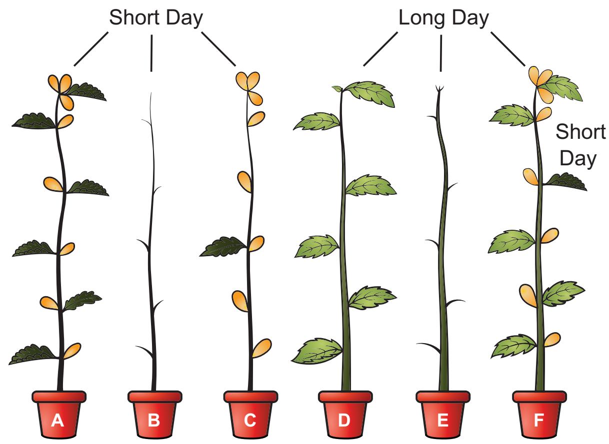


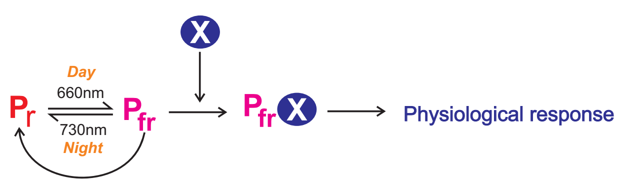
Figure 15.15: Experiment on Cocklebur plant showing photoperiodic stimulus

The nature of flower producing stimulus has been elusive so far. It is believed by many physiologists that it is a hormone called **florigen**. The term florigen was coined by **Chailakyan** (1936) but it is not possible to isolate.

4. Importance of photoperiodism

1. The knowledge of photoperiodism plays an important role in hybridisation experiments.
2. Photoperiodism is an excellent example of physiological pre-conditioning that is using an external factor to induce physiological changes in the plant.

5. Phytochrome



Phytochrome is a bluish biliprotein pigment responsible for the perception of light in photo physiological process. **Butler *et al.*,** (1959) named this pigment and it exists in two interconvertible forms:

Photoperiodism in plants

Pioneers of photoperiodism
Garner and Allard (1920)

Long day plants

The plants that require long critical day length for flowering

Short long day plants

These are long day plants but should be exposed to short day lengths during early period of growth for flowering.
Wheat and Rye

Plants which can flower in all possible photoperiods. They are also called **photo neutrals** or **indeterminate plants. Potato, *Rhododendron***

Day neutral plants

Intermediate plants

Plants require a photoperiod between long day and short day for flowering

A short-day plant but they have to be exposed to long days during their early periods of growth for flowering.
***Bryophyllum* and Night jasmine**

Long short day plants

The plants that require a short critical day length for flowering or long night plants

Short day plants

(i) red light absorbing pigment which is designated as P_r and (ii) far red light absorbing pigment which is designated as P_{fr}. The P_r form absorbs red light in 660nm and changes to P_{fr}. The P_{fr} form absorbs far red light in 730nm and changes to P_r. The P_r form is biologically inactive and it is stable whereas P_{fr} form is biologically active and it is very unstable. In short day plants, P_r promotes flowering and P_{fr} inhibits the flowering whereas in long day plants flowering is promoted by P_{fr} and inhibited by P_r form. P_{fr} is always associated with hydrophobic area of membrane systems while P_r is found in diffused state in the cytoplasm. The interconversion of the two forms of phytochrome is mainly involved in flower induction and also additionally plays a role in seed germination and changes in membrane conformation.

15.4 Vernalization (*Vernal* – Spring Like)

Besides photoperiod certain plants require a low temperature exposure in their earlier stages for flowering. Many species of biennials and perennials are induced to flower by low temperature exposure (0°C to 5°C). This process is called **Vernalization.** The term Vernalization was first used by **T. D. Lysenko** (1938).

1. Mechanism of Vernalization:

Two main theories to explain the mechanism of vernalization are:

i. Hypothesis of phasic development
ii. Hypothesis of hormonal involvement

i. Hypothesis of phasic development

According to Lysenko, development of an annual seed plant consists of two phases. First phase is **thermostage**, which is vegetative phase requiring low temperature and suitable moisture. Next phase is **photo stage** which requires high temperature for synthesis of florigen (flowering hormone).

ii. Hypothesis of hormonal involvement

According to **Purvis** (1961), formation of a substance A from its precursor, is converted into B after chilling. The substance B is unstable. At suitable temperature B is converted into stable compound D called **Vernalin**. Vernalin is converted to F (Florigen). Florigen induces flower formation. At high temperature B is converted to C and devernalization occurs (Figure 15.16).

2. Technique of Vernalization:

The seeds are first soaked in water and allowed to germinate at 10°C to 12°C. Then seeds are transferred to low temperature (3°C to 5°C) from few days to 30 days. Germinated seeds after this treatment are allowed to dry and then sown. The plants will show quick flowering when compared to untreated control plants.

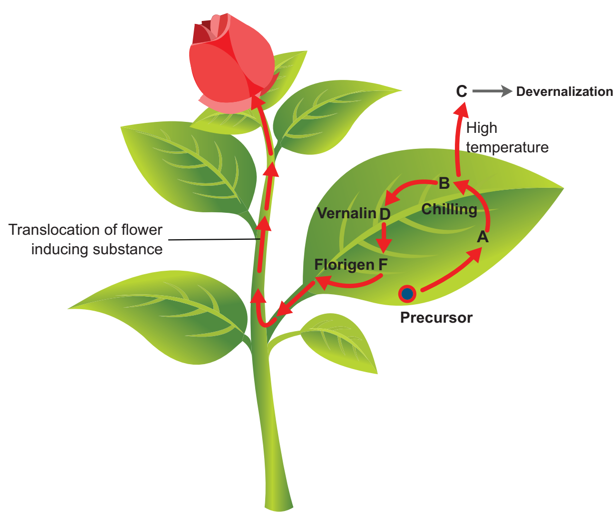


Figure 15.16: Vernalization and Flowering

3. Devernalization

Reversal of the effect of vernalization is called **devernalization**.

4. Practical applications

1. Vernalization shortens the vegetative period and induces the plant to flower earlier.
2. It increases the cold resistance of the plants.
3. It increases the resistance of plants to fungal disease.
4. Plant breeding can be accelerated.

15.5 Seed Germination and Dormancy

I. Seed Germination

The activation and growth of embryo from seed into seedling during favourable conditions is called **seed germination**.

1. Types of germination

There are two methods of seed germination. Epigeal and hypogeal.

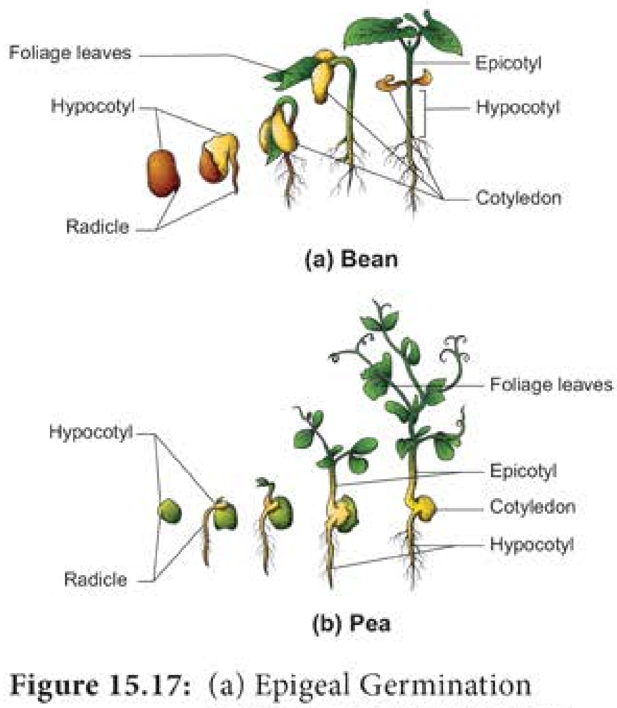


Figure 15.17: (a) Epigeal Germination
(b) Hypogeal Germination

i. Epigeal germination

During epigeal germination cotyledons are pushed out of the soil. This happens due to the elongation of the hypocotyl. Example: Castor and Bean.

ii. Hypogeal germination

During hypogeal germination cotyledons remain below the soil due to rapid elongation of epicotyls (Figure 15.17). Example: Maize

2. Factors affecting germination

Seed germination is directly affected by external and internal factors:

i. External factors

a. **Water**: It activates the enzymes which digest the complex reserve foods of the seed. If the water content of the seed goes below a critical level, seeds fail to germinate.

b. **Temperature**: Seeds fails to germinate at very low and high temperature. The optimum temperature is 25°C to 35°C for most tropic species.

c. **Oxygen**: It is necessary for germination. Since aerobic respiration is a physiological requirement for germination most will germinate well in air containing 20% oxygen.

d. **Light**: There are many seeds which respond to light for germination and these seeds said to be photoblastic.

e. **Soil conditions**: Germination of seed in its natural habit is influenced by soil conditions such as water holding capacity, mineral composition and aeration of the soil.

ii. Internal factors

a. **Maturity of embryo**: The seeds of some plants, when shed will contain immature embryo. Such seeds germinate only after maturation of embryo.

b. **Viability**: Usually seeds remain viable or living only for a particular period. Viability of seeds range from a few days (Example: *Oxalis*) to more than hundred years. Maximum viability (1000 years) has been recorded in lotus seeds. Seeds germinate only within the period of viability.

c. **Dormancy**: Seeds of many plants are dormant at the time of shedding. A detailed treatment is given below.

II. Seed Dormancy

The seeds of most plants germinate under favourable environmental conditions but some seeds do not germinate when suitable conditions like water, oxygen and favourable temperature are not available. Germination of such seeds may be delayed for days, months or years. The condition of a seed when it fails to germinate even in suitable environmental condition is called **seed dormancy**. There are two main reasons for the development of dormancy: Imposed dormancy and innate dormancy. Imposed dormancy is due to low moisture and low temperature. Innate dormancy is related to the properties of seed itself.

1. Factors causing dormancy of seeds:

i. Hard, tough seed coat causes barrier effect as impermeability of water, gas and restriction of the expansion of embryo prevents seed germination.

ii. Many species of seeds produce imperfectly developed embryos called **rudimentary embryos** which promotes dormancy.

iii. Lack of specific light requirement leads to seed dormancy.

iv. A range of temperatures either higher or lower cause dormancy.

v. The presence of inhibitors like phenolic compounds which inhibits seed germination cause dormancy.

2. Methods of breaking dormancy:

The dormancy of seeds can be broken by different methods. These are:

i. **Scarification**: Mechanical and chemical treatments like cutting or chipping of hard tough seed coat and use of organic solvents to remove waxy or fatty compounds are called as **Scarification**.

ii. **Impaction**: In some seeds water and oxygen are unable to penetrate micropyle due to blockage by cork cells. These seeds are shaken vigorously to remove the plug which is called **Impaction**.

iii. **Stratification**: Seeds of rosaceous plants (Apple, Plum, Peach and Cherry) will not germinate until they have been exposed to well aerated, moist condition under low temperature ($0^{\circ}C$ to $10^{\circ}C$) for weeks to months. Such treatment is called **Stratification**.

iv. **Alternating temperatures**: Germination of some seeds is strongly promoted by alternating daily temperatures. An alternation of low and high temperature improves the germination of seeds.

v. **Light**: The dormancy of photoblastic seeds can be broken by exposing them to red light.

15.6 Senescence

Plant life comprises some sequential events, *viz*: germination, juvenile stage, maturation, old age and death. Old age is called **senescence** in plants. Senescence refers to all collective, progressive and deteriorative processes which ultimately lead to complete loss of organization and function. Unlike animals, plants continuously form new organs and older organs undergo a highly regulated senescence program to maximize nutrient export.

1. Types of Senescence

Leopold (1961) has recognised four types of senescence:

i. Overall senescence
ii. Top senescence
iii. Deciduous senescence
iv. Progressive senescence

> The branch of botany which deals with ageing, abscission and senescence is called **Phytogerontology**

i. **Overall senescence**: This kind of senescence occurs in annual plants when entire plant gets affected and dies. Example: Wheat and Soybean. It also occurs in few perennials also. Example: *Agave* and Bamboo.

ii. **Top senescence**: It occurs in aerial parts of plants. It is common in perennials, underground and root system remains viable. Example: Banana and *Gladiolus*.

iii. **Deciduous senescence**: It is common in deciduous plants and occurs only in leaves of plants, bulk of the stem and root system remains alive. Example: Elm and Maple.

iv. **Progressive senescence**: This kind of senescence is gradual. First it occurs in old leaves followed by new leaves then stem and finally root system. It is common in annuals (Figure 15.18).

2. Physiology of Senescence

- Cells undergo changes in structure.
- Vacuole of the cell acts as lysosome and secretes hydrolytic enzymes.
- The starch content is decreased in the cells.
- Photosynthesis is reduced due to loss of chlorophyll accompanied by synthesis and accumulation of anthocyanin pigments, therefore the leaf becomes red.

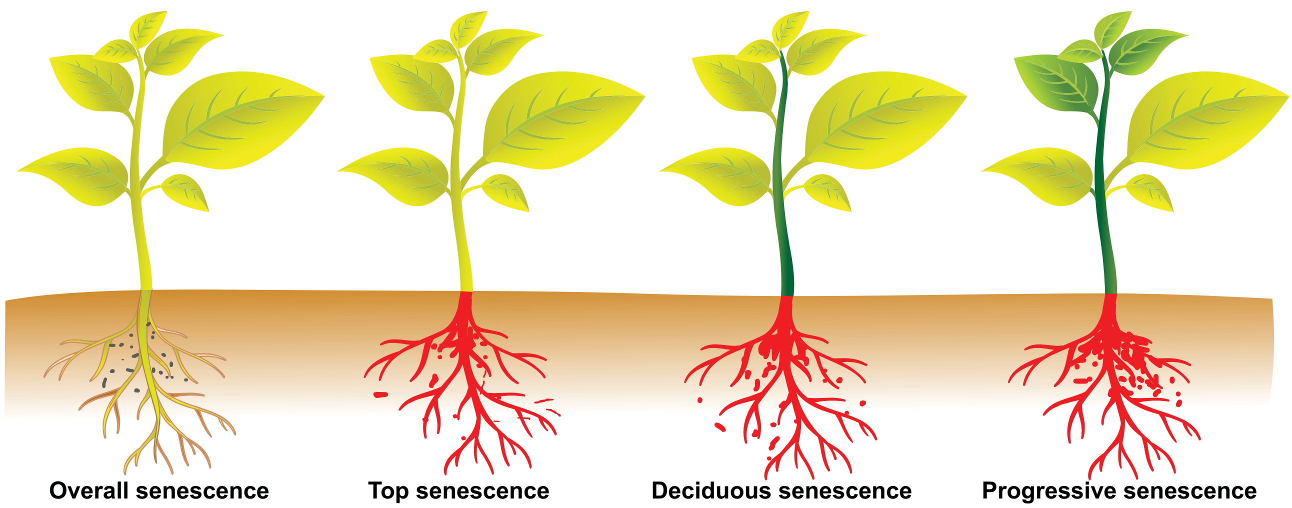


Figure 15.18: Different types of senescence in plants

- There is a marked decrease in protein content in the senescing organ.
- RNA content of the leaf particularly rRNA level is decreased in the cells due to increased activity of the enzyme RNAase.
- DNA molecules in senescencing leaves degenerate by the increased activity of enzyme DNAase.

3. Factors affecting Senescence:

- ABA and ethylene accelerate senescence while auxin and cytokinin retard senescence.
- Nitrogen deficiency increases senescence whereas nitrogen supply retards senescence.
- High temperature accelerates senescence but low temperature retards senescence.
- Senescence is rapid in dark than in light.
- Water stress leads to accumulation of ABA leading to senescence.

4. Programmed cell death (PCD)

Senescence is controlled by plants own genetic programme and death of the plant or plant part consequent to senescence is called **Programmed Cell Death**. In short senescence of an individual cell is called **PCD**. The proteolytic enzymes involving PCD in plants are **phytaspases** and in animals are **caspases**. The nutrients and other substrates from senescing cells and tissues are remobilized and reallocated to other parts of the plant that survives. The protoplasts of developing xylem vessels and tracheids die and disappear at maturity to make them functionally efficient to conduct water for transport. In aquatic plants, aerenchyma is normally formed in different parts of the plant such as roots and stems which encloses large air spaces that are created through PCD. In the development of unisexual flowers, male and female flowers are present in earlier stages, but only one of these two completes its development while other aborts through PCD (Figure 15.19).

5. Abscission

Abscission is a physiological process of shedding of organs like leaves, flowers, fruits and seeds from the parent plant body. When these parts are removed the plant seals off its vascular system to prevent loss of water and nutrients. Final stage of senescence is abscission. In temperate regions all the leaves of deciduous plants fall in autumn and give rise to naked appearance, then the new leaves are developed in the subsequent spring season. But in evergreen plants there is gradual abscission of leaves, the older leaves fall while new leaves are developed continuously throughout the year.

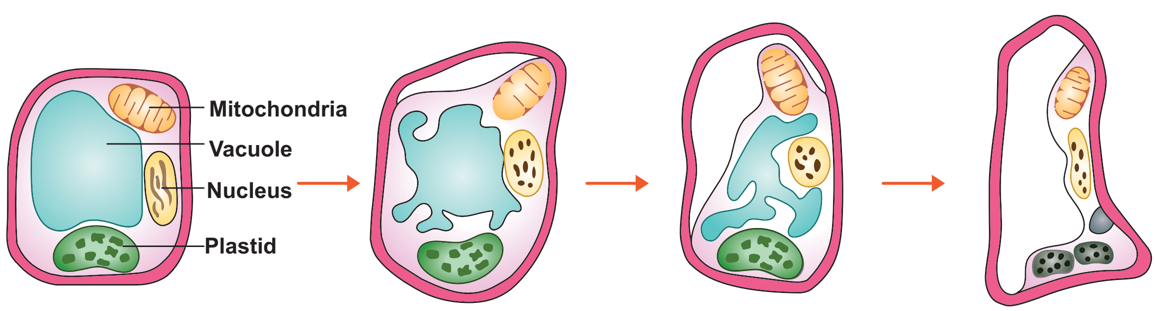


Figure 15.19: Programmed cell death

6. Morphological and Anatomical changes during abscission

Leaf abscission takes place at the base of petiole which is marked internally by a distinct zone of few layers of thin walled cells arranged transversely. This zone is called **abscission zone or abscission layer**. An abscission layer is greenish-grey in colour and is formed by rows of cells of 2 to 15 cells thick. The cells of abscission layer separate due to dissolution of middle lamella and primary wall of cells by the activity of enzymes **pectinase** and **cellulase** resulting in loosening of cells. Tyloses are also formed blocking the conducting vessels. Degrading of chlorophyll occur leading to the change in the colour of leaves, leaf detachment from the plant and leaf fall. After abscission, outer layer of cells becomes suberized by the development of periderm (Figure 15.20).

7. Hormones influencing abscission

All naturally occurring hormones influence the process of abscission. Auxins

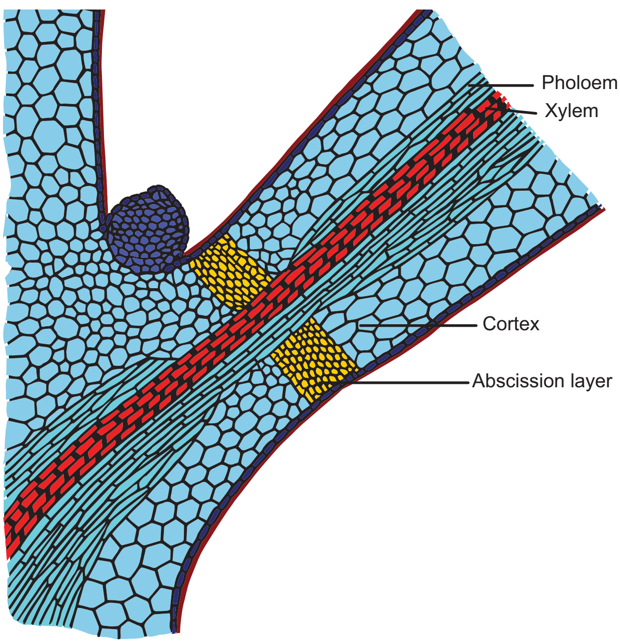


Figure 15.20: a) L.S of petiolar base showing abscission layer

and cytokinins retard abscission, while abscisic acid (ABA) and ethylene induce it.

8. Significance of abscission

1. Abscission separates dead parts of the plant, like old leaves and ripe fruits.
2. It helps in dispersal of fruits and continuing the life cycle of the plant.
3. Abscission of leaves in deciduous plants helps in water conservation during summer.
4. In lower plants, shedding of vegetative parts like gemmae or plantlets help in vegetative reproduction.

Summary

Growth occurs by cell division, cell elongation and cell maturation. The first phase is lag phase, the second is log phase and the final phase is steady state phase. The log phase is otherwise known as **exponential phase**. The three phases are collectively called Grand period of growth. Plant exhibits plasticity in development. Plant growth and development are controlled by both internal and external factors. The internal factors are chemical substances called Plant Growth Regulators (PGRs). The hormones are classified into five groups: Auxins, gibberellins, cytokinins, abscisic acid and ethylene. These PGRs are synthesized in various parts of the plant. PGRs may act synergistically or antagonistically. The external factors affecting growth includes water, nutrition, temperature, oxygen and light. Mechanism of flowering is controlled by light period (photoperiodism) and temperature (vernalization). The physiological changes on flowering with effect from relative length of light and darkness (photoperiodism) are called photoperiodism. A bluish biliprotein responsible for the perception of light in photophysiological process (induction and inhibition of flowering) is called **Phytochrome**. Besides photoperiod certain plants require a low temperature in the earlier stages for flowering. Many biennial and perennial plants are induced to flower by low temperature ($0^{o}C$ to $5^{o}C$). This process is called **vernalization** and the reversal effect of vernalization is called **devernalization**. The condition of a seed when it fails to germinate even in suitable environmental condition is called **seed dormancy**. Thus, dormancy can be overcome by following methods such as scarification, impaction, stratification, alternating temperatures and light. Senescence refers to all collective, progressive and deteriorative processes which ultimately lead to complete loss of organization and function. Senescence is of four types and they are overall, top, deciduous and progressive. Senescence is controlled by plant's own genetic programme. Death of the plant or its parts consequent to senescence is called **Programmed Cell Death** (PCD). The final stage of senescence is abscission. Abscission is a physiological process of shedding of organs from the parent plant body.

Evaluation

CRU5PV

1. Select the wrong statement from the following:
   a. Formative phase of the cells retain the capability of cell division.
   b. In elongation phase development of central vacuole takes place.
   c. In maturation phase thickening and differentiation takes place.
   d. In maturation phase, the cells grow further.
2. If the diameter of the pulley is 6 inches, length of pointer is 10 inches and distance travelled by pointer is 5 inches. Calculate the actual growth in length of plant.
   a. 3inches b. 6 inches
   c. 12 inches d. 30 inches
3. In unisexual plants, sex can be changed by the application of
   a. Ethanol b. Cytokinins
   c. ABA d. Auxin
4. Select the correctly matched one

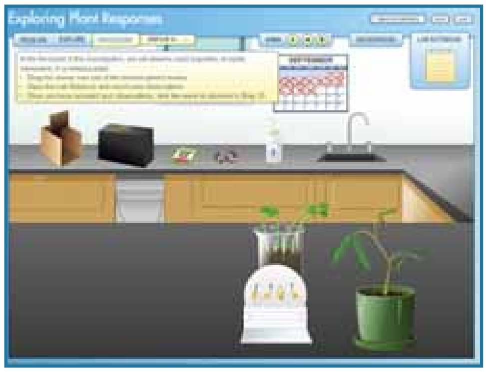
A) Human urine	i) Auxin –B
B) Corn gram oil	ii) GA_3
C) Fungus	iii) Abscisic acid II
D) Herring fish sperm	iv) Kinitin
E) Unripe maize grains	v) Auxin A
F) Young cotton bolls	vi) Zeatin

   a) A-iii, B-iv, C-v, D-vi, E-i, F-ii,
   b) A-v, B-i, C-ii, D-iv, E-vi, F-iii,
   c) A-iii, B-v, C-vi, D-i, E-ii, F-iv,
   d) A-ii, B-iii, C-v, D-vi, E-iv, F-i
5. Seed dormancy allows the plants to
   a. overcome unfavourable climatic conditions
   b. develop healthy seeds
   c. reduce viability
   d. prevent deterioration of seeds
6. What are the parameters used to measure growth of plants?
7. What is plasticity?
8. Write the physiological effects of Cytokinins.
9. Describe the mechanism of photoperiodic induction of flowering.
10. Give a brief account on Programmed Cell Death (PCD)

ICT Corner

How do Plants respond to different stimuli?

Let's Stimulate **the Plants.** →

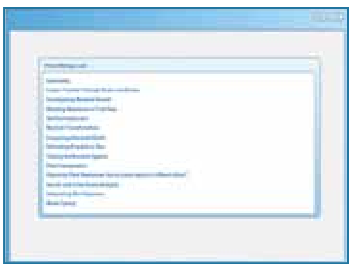


Steps

- Scan the QR code
- Click Exploring plant responses
- Select items and complete the check list
- Follow the procedure – 1 to 10 steps
- Record your prediction and not your observation in lab note – Right top

Activity

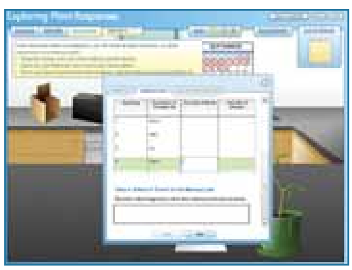
- Observe the movements of plant seedlings and plant parts.
- Conclude your observations.



Step 1

Step 2

Step 3



Step 4

Web URL:

https://www.classzone.com/books/hs/ca/sc/bio_07/virtual_labs/virtualLabs.html

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* Pictures are indicative only