PLANT GROWTH AND DEVELOPMENT

INTRODUCTION

- **Growth** is a characteristic feature of all living organisms.
- Growth is a vital process which brings about permanent and irreversible changes in any plant or its parts.
- Growth is the final product of successful metabolism, i.e., during growth, anabolic process dominate over catabolic process.
- Growth is diffused in animals but growth in plants is localised and irregular.
- **Development** is a process in which cells change form & function to form the specialized tissues, organ & structure required during the life cycle of a plant. It commences with the first cell division after fertilization of the ovule & continues through seed development, seed germination, the development of the seedlings to the mature plant, flowering & production of next generation of ovules. It also includes the processes of cell death & senescence. During this period, a complex body organisation is formed that produces roots, leaves, branches, flowers, fruits & seeds & finally dies.

PLANT GROWTH

GROWTH IS GENERALLY INDETERMINATE

- Plant growth is unique because plants retain the capacity for unlimited growth throughout their life. This ability of plants is due to the presence of meristems at certain locations in their body. The cells of such meristems have a capacity to divide and self perpetuate. These cells later form plant body when they lose the capacity of dividing.
- Some plant structures are determinate while others are indeterminate. A determinate structures grows to a certain size and then stops, eventually undergoing senescence and death (e.g. leaves, flowers and fruits). On the other hand, the vegetative stems and roots are indeterminate structures. They grow by meristems that continuously replenish themselves. When an indeterminate vegetative meristem becomes reproductive (i.e., begins to form a flower), it becomes determinate.
- There are three meristematic regions in plant i.e., **apical**, **intercalary** and **lateral**.
  - **Apical meristems** : These meristems are found at shoot and root apex. As a result of activity of these meristems plant increases in length. In angiosperms, and gymnosperms there is a group of meristematic cells but in bryophytes and pteridophytes there is a single tetrahedral cell found at the shoot apex.
  - **Intercalary meristems** : These meristems are found above the nodes. As a result of the activity of these meristems plants increase in length, e.g., Bambusa.
  - **Lateral meristems** : These meristems are made up of cells which divide in radial direction only. Cork cambium (phellogen) and vascular cambium are the examples of lateral meristems. Increase in girth of shoots and roots take place because of the activity of this cambium.

GROWTH IS MEASURABLE

- Growth is a result of increase in the amount of protoplasm. It is difficult to measure the amount of protoplasm but growth is measured by a variety of parameters which is more or less proportional to the amount of protoplasm.
- Growth in plants means increase in shape, size, weight and volume of a plant or plant part. Growth leads to increase in fresh weight, dry weight, length, area, volume and cell number and all these are controlled **extrinsically** (by environmental factors) and **intrinsically** (by nucleus and protoplasm).

PHASES OF GROWTH

- **Phase of cell formation** : This phase is limited to the apex of shoot and root meristems. Cells of this region continuously divide and increase in number. The cells in this region are rich in protoplasm, possess large conspicuous nuclei and thin cellulosic walls.
- **Phase of cell elongation** : This phase is found exactly below the cells of phase of cell formation. In this phase, small vacuoles are formed in which water and dissolved matter are collected and at the end, all vacuoles unite to form a big vacuole. A big vacuole is situated at the centre, nucleus and cytoplasm are situated as a thin layer at the internal layer of cell-wall, called primordial utricle.
- **Phase of cell maturation or differentiation phase** : Cell differentiation following cell division and cell enlargement leads to the development of specialized mature tissue cell, e.g., some cells are differentiated into xylem tracheids and trachea and some others into sieve tubes and companion cells.

PLANT GROWTH RATE

Plant Growth Rate refers to **increase in growth per unit time**.

It is of two types :

ARITHMETIC GROWTH

From a dividing cell, two new cells are formed (by mitotic division), out of them one daughter cell continues to divide while other differentiates and matures (stops dividing) .

E.g. Root and shoot elongation at constant rate.

It is mathematically expressed as

$$L_t = L_0 + rt$$

where L_t = length at time 't'

L_0 = length at time 'zero'

r = growth rate/elongation per unit time.

On plotting the growth against time, a linear curve is obtained.

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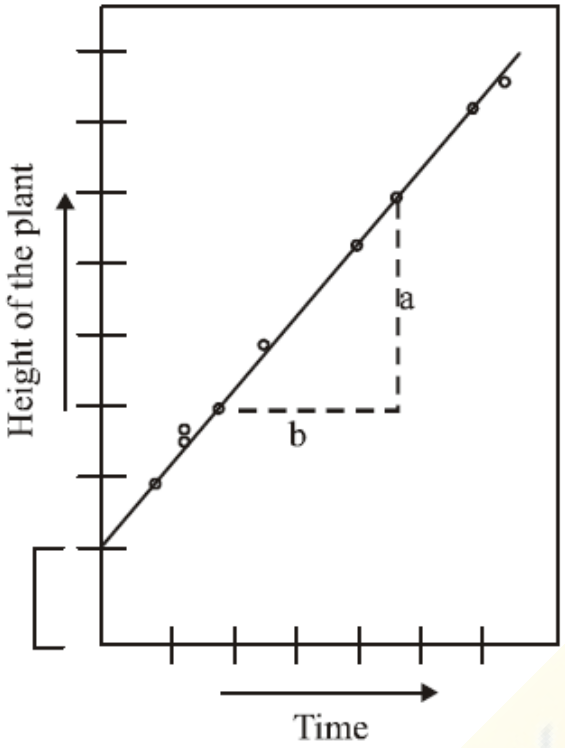


Fig. : Constant linear growth, a plot of length *L* against time *t*.

GEOMETRIC / EXPONENTIAL GROWTH

From dividing cell (by mitotic division) both daughter cells retain the ability to divide and continue to do so.

E.g. : All cells, tissues, organs, developing seeds, germinating seeds, seasonal activities etc.

It is mathematically represented as

$$W_1 = W_0 e^{rt}$$

Where,

W_1 = final size (weight, height, number etc.)

W_0 = initial size at the beginning of period.

r = growth rate, e = base of natural logarithms.

t = time of growth

On plotting the growth against time, a typical sigmoid or S-curve is obtained.

It has 3 phases :

- **Lag period phase** : In lag period, the growth is slow. It represents the formative or cell division phase.

- **Log phase/Exponential phase** : During this phase growth is maximum and most rapid. It represents cell elongation phase.
- **Steady State phase** : It represents cell maturation phase.

Time taken in growth phases (mainly log phase) is called as grand period of growth.

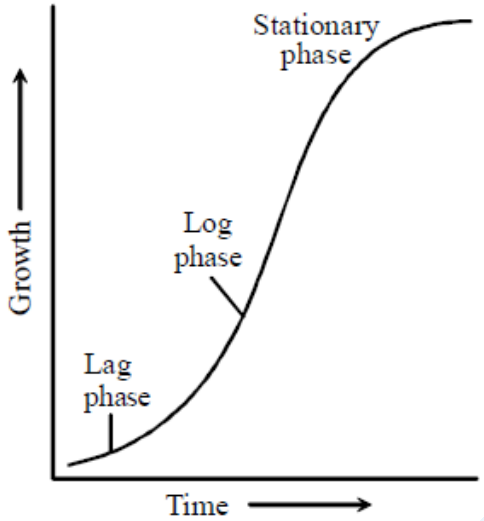


Fig. : A typical S-shaped grand period of growth curve

Quantitative comparisons between growth of living system can be done by the following methods :

- **Absolute growth rate** : Measurement and the comparison of total growth per unit time in plant or plant parts.
- **Relative growth rate** : The growth of the given system per unit time expressed on a common basis i.e. per unit initial parameter in plant parts.

Relative growth rate is generally high in young developing plant parts.

MEASUREMENT OF GROWTH

The following methods are designed to measure growth in length.

- **Bose's direct method** : Measurement is done between two marked points by a scale at regular intervals.
- **Bose's horizontal microscope**
- **Bose's crescograph** : It magnifies growth by 10,000 times.
- **Auxanometers**
  - Arc Auxanometer
  - Pfeffer's Auxanometer
  - Micrometer Screw Auxanometer

EFFICIENCY INDEX (E.I.)

Growth can be measured by an increase in size or area of an organ of the plant (leaf, flower, fruit etc.) in a unit time and is called as efficiency index. E.I. may be same or different from species to species and organ to organ.

FACTORS AFFECTING PLANT GROWTH

- **Light** : Light is involved in photosynthesis and determines the direction of shoot and root growth. Light controlled morphogenesis of plant is called photomorphogenesis. In absence of light plant exhibit etiolation.
- **Temperature** : Optimum temp. for growth is 20-35°C. temp. Above 45°C damages the protoplasm and growth is retarted. Effect of low temperature on flowering is called vernalization.
- **Water** : Water maintains the turgidity of cell, which is essential for growth. TP is important for growth. In order for a cell to grow ψ_w must not be allowed to reach zero. Water is essential for the enzyme activity in protoplasm.
- **Oxygen** : It is necessary for cell respiration.
- **Mineral nutrients** : All essential elements are compulsory for growth and metabolism.
- **Pollutants** : Several pollutants such as automobile exhaust, peroxyacetyl nitrate (PAN), pesticides etc. have detrimental effect on plant growth. Citrus and Gladiolus are very sensitive to fluorides. Poor growth of tobacco is observed in regions where ozone concentration is high.
- **Carbon dioxide** : CO_2 is essential for photosynthesis and hence it is essential for nutrition also. Due to change in photosynthetic rate, with the increase or decrease in CO_2 concentration, the plant growth is also affected.
- **Nutrition** : It provides the raw material for growth and differentiation and is a source of energy.
- **Growth regulators** : These are manufactured by living protoplasm and are important internal growth regulators which are essential for growth and development.

DIFFERENTIATION, DE-DIFFERENTIATION AND RE-DIFFERENTIATION

- **Differentiation** : Cells derived from active meristem tissue become mature to perform specific function.

Differentiation is applied to the qualitative differences between cells, tissues and organs.
During differentiation, cells undergo few to major anatomical and physiological changes both in their cell walls and protoplasm.

- **Dedifferentiation** : In plants, the living differentiated cell which had lost the capacity of cell division are able to, regain the capacity of cell division under certain conditions called dedifferentiation. E.g. Formation of meristems intrafascicular cambium & cork from differentiated parenchyma cells.
- **Redifferentiation** : The regain of differentiation capacity by losing the capacity of cell division for performing specific function by dedifferentiated cells.

DEVELOPMENT

Development is a term that includes all changes that an organism goes through during its life cycle from germination of the seeds to senescence.

In different phases of growth, plants follow different pathways and form different kinds of structures in response to environment. The ability to change under the influence of internal or external stimuli is called **plasticity**, e.g., heterophylly in cotton, coriander and larkspur. Occurrence of different types of structures on the same plant in different growth phases or under different environmental conditions is known as

heterophylly. On the other hand, differences in the shape of leaves produced in air and those produced in water in buttercup also represents the heterophyllous development due to environment.

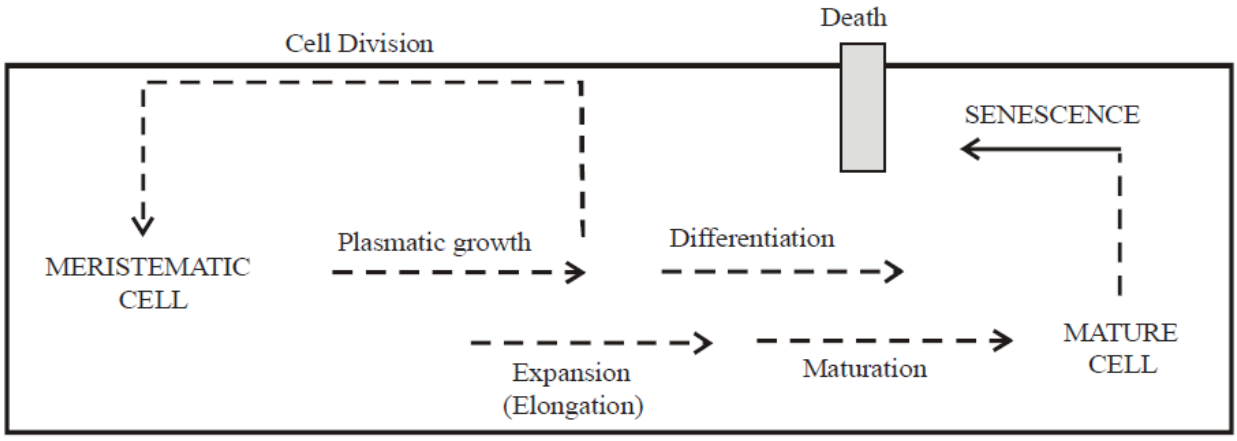


Fig. : Sequence of the developmental process in a plant cell

PLANT GROWTH REGULATORS

- **Plant hormone** is a chemical substance which may be translocated to another region, for regulating one or more physiological reactions when present in low concentration.
- **All phytohormones are growth regulators** but **all growth regulators are not phytohormones**.
- Plant growth regulators are grouped into two categories based on the nature of their actions
  - **Plant growth promoters**, e.g., auxins, cytokinins, gibberellins.

They promote growth activities like cell division, cell enlargement, flowering, fruiting and seed formation, etc.

  - **Plant growth inhibitors**, e.g., abscisic acid (ABA) and ethylene.

They play an important role in plant response to wounds and stresses of biotic and abiotic origin. They are involved in growth inhibiting activities such as dormancy and abscission.

AUXINS

- **Charles Darwin & F. Darwin** (1880) were the first to study phototropism.

Darwin found that the light falling on the tip of Canary grass (Phalaris canariensis) coleoptile from one side causes some influence to be transmitted downwards due to which the coleoptiles curve towards the light.

- **Boysen & Jensen** (1910) : They performed experiments on oat (Avena sativa) plant. In the first experiment, he removed the coleoptile tip and then replaced it on stump. On providing unilateral light the coleoptile tip gave positive curvature. They observed that if gelatin is inserted between the tip & stump is cut, then coleoptile bends towards the unilateral light. If mica were inserted then the coleoptile fails to show phototropism .
- **F.W. Went** (1928) : Went isolated the growing tip of Avena sativa on agar plate & performed Agar-block experiment. He gave the name auxin to growth substance, thus credit of auxin discovery goes to F.W. Went. He also found that the curvature (bending) in Avena coleoptile is proportional, within limits to the amount of auxin in agar - block. This test was named as Avena curvature-test (Bioassay of auxin).

Went found that 27% auxin present on illuminated side and 57% on the dark side. (About 16% auxin lost on illuminated side and rest transferred to base). Transport of natural auxin is basipetal and polar type.

- **Kogl and Haagensmit** (1931) : They isolated an active substance from urine of a pellagra patient which was called as Auxin - A or chemically auxenotriolic acid ($C_{18}H_{32}O_5$).

Later a similar substance was isolated from corn grain oil and was named as auxin-B or auxenolonic acid. ($C_{18}H_{30}O_4$).

- **Again Kogl, Erxleben and Haagen Smit** 1934 - isolated another substance from human urine and it named as heteroauxin (IAA-$C_{10}H_9O_2N$).
- Auxin from Rhizopus was **obtained by Thimann**.

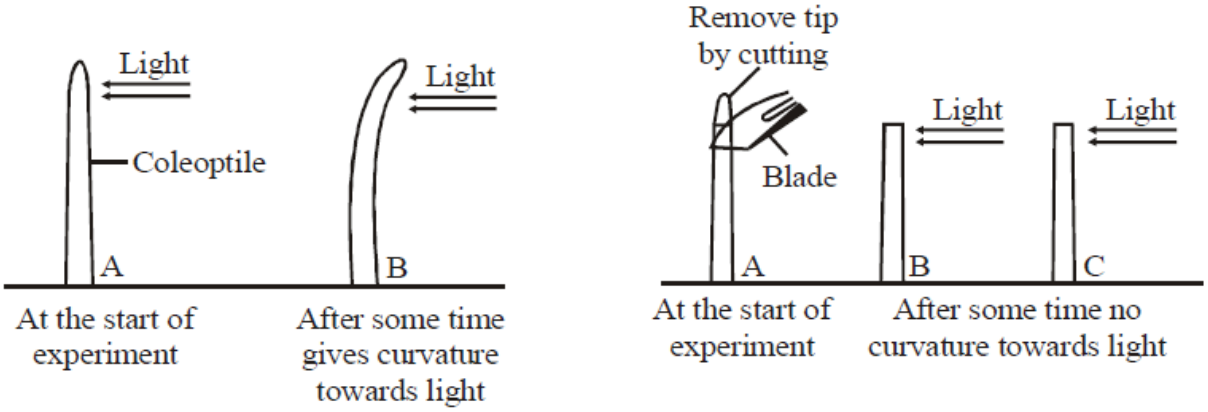


Fig. : Discovery of auxins (Darwin's experiments)

- Auxin biosynthesis occurs by **tryptophan amino acid** in the presence of Zn^{++} ion.
- **Degradation or oxidation of auxin** is by-
  - Enzymatic (by IAA oxidase) reaction.
  - Photo-oxidation reaction.
- Now IBA (Indole Butyric acid) have also been isolated from plants (natural auxin) but IAA is most widely found auxin in plants.
- The compounds which can be converted into auxins are called **auxin precursors**, whereas the compounds which inhibit the activity of auxin are called as **antiauxins**.
- **Natural auxins** : These are naturally occurring auxins in plants and therefore are regarded as phytohormones. Indole 3-acetic acid (IAA) is the best known and universal auxin. It is found in all plants and fungi.

Besides IAA, indole-3-acetaldehyde, indole-3-pyruvic acid, indole ethanol, 4-chloro-indole acetic acid (4-chloro-IAA) etc., are some other natural auxins.

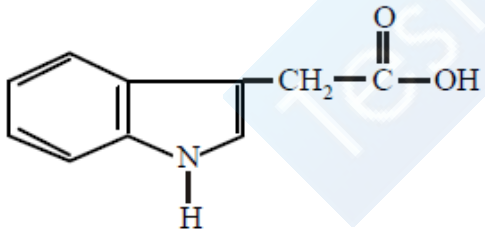
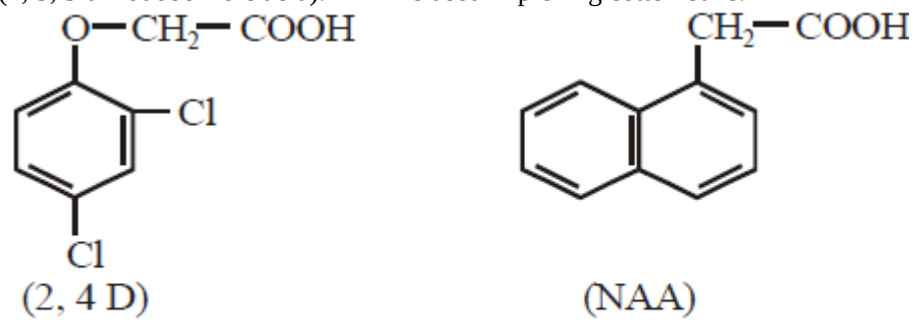


Fig. : Indole acetic acid (IAA)

Natural auxins are synthesized in physiologically active parts of plants such as shoot apices, leaf primordia and developing seeds, buds (apex), embryos, from amino acid tryptophan. In root apices, they are synthesized in relatively very small amount. Auxins show polar movement. It is basipetal (from apex to base) in stem but acropetal (from root tip towards shoot) in the root. Auxins move slowly by diffusion from cell to cell and not through the vascular tissues. Auxins help in the elongation of both roots and shoots.

- **Synthetic auxins** : These are synthetic compounds which cause various physiological responses common to IAA. Some of the important synthetic auxins are 2, 4-D
(2, 4-dichlorophenoxy acetic acid) is the weedicide, 2, 4,
5-T (2, 4, 5-trichlorophenoxy acetic acid), IBA (indole 3-butyric acid), NAA (Naphthalene acetic acid, PAA (Phenyl acetic acid), IPA (Indole 3-propionic acid). IBA is both natural and synthetic auxin.

Certain compounds which inhibit action of auxin and compete with auxins for active sites are called antiauxins. E.g., PCIB (p- chlorophenoxy isobutyric acid), TIBA
(2, 3, 5-tri iodobenzoic acid). TIBA is used in picking cotton balls.



(2, 4 D) (NAA)

Fig. : Synthetic auxins

PHYSIOLOGICAL EFFECTS AND ITS APPLICATIONS

- **Apical dominance** : In most higher plants, the growing apical bud inhibits the growth of the lateral (axillary) buds, a phenomenon called apical dominance. Removal of shoot tips (decapitation) usually results in the growth of lateral buds. It is widely applied in tea plantations, hedge-making.
- **Cell division & cell enlargement** : Auxin is important in tissue culture and grafting. It stimulates division of intrafascicular cambium and also in healing of wounds.
- **Shortening of internodes** : α-NAA induces the formation of dwarf shoot or spurs in apple, pear etc., thus number of fruits increases.
- **Prevention of lodging** : Auxin spray prevents lodging of crops, immature leaves and fruits.
- **Root initiation** : Rooting on stem cuttings is promoted by IBA and NAA (Root growth is inhibited by auxin).
- **Prevention of Abscission** : IAA, NAA prevents premature abscission of plant organs.
- **Flower initiation** : Auxin is inhibitor of flowering but it promotes uniform flowering in pineapple and litchi plants.
- **Parthenocarpy** : In fruits like orange, lemon, grapes, bananas etc. fruits can be developed without pollination and fertilization. They are seedless fruits. If stamens are removed from flower bud and auxin paste is applied to the stigma of the flower seedless fruits develop.
- **Selective weed killer** : Weeds are the unwanted plants growing in a field along with a crop. These weeds cause competition for water, minerals, light and space and thus do not allow proper growth of the crop. Hence, these unwanted plants should be removed from the crop mechanically or by other methods. One of these methods is the spray of auxins like 2, 4-D.
- **Femaleness** : Feminising effect in some plants.
- **Flower and Fruit thinning** : Certain trees like mango form less number of fruits in alternate years. But auxin use can produce normal fruit crops every year.
- When antiauxin (TIBA-Tri-Iodo-Benzoic acid) is sprayed on mature cotton field then cotton balls can be picked easily.

BIO-ASSAY

Bioassay means testing of substance for it's activity in causing a growth response in a living plant or it's parts.

- Avena curvature test : Avena curvature test carried out by F.W. Went (1928), demonstrated the effect of auxins on plant growth while performing some experiments with oat (Avena sativa) coleoptile.
- Root growth inhibition test, is a bioassay for examining auxin activity.

GIBBERELLIN

- In Japan, farmers observed peculiar symptoms in rice seedlings (highly tall, thin, yellowish, weak) and called it the bakanae disease (foolish seedling disease) of rice seedlings.

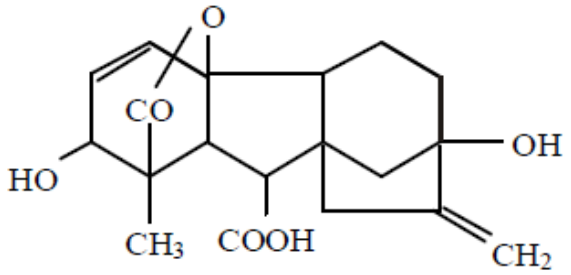


Fig. : Gibberellic acid

- The cause of this disease is the fungi Gibberella (Ascomycetes) or Fusarium (Deuteromycetes) as confirmed by Kurosawa and Swada.
- **Yabuta and Sumiki** 1938 were first to extract a crystalline substance from the Gibberella fungus, which they named as Gibberellin.
- Gibberellin is acidic and possess a gibben ring structure that are able to overcome genetic dwarfism in plants.
- 100 types of gibberellins (GA_1, GA_2, GA_3, ... GA_{100}) are known . GA_3 [$C_{19}H_{26}O_6$] is representative of all Gibberellins. First discovered Gibberellins from higher plants was GA_1 (GA_1 and GA_{20} are common GA's of higher plants).
- GA found in all group of plants (algae to angiosperms) but as a flowering hormone acts only in angiosperms.
- Biosynthesis of gibberellin takes places by **mevalonic acid pathway** (Kaurene → GA).
- GA moves through xylem and phloem and the movement is non-polar so they tend to affect the whole plant.

PHYSIOLOGICAL EFFECTS AND ITS APPLICATIONS

- **Stem/internode elongation (characteristic function of gibberellins)** : GA induces internode elongation, leaf expansion & is used in sugarcane cultivation. Gibberellins induce stem elongation in rosette plants (Cabbage). This phenomenon known as bolting effect.
- **Elongation of genetic dwarf plants** : When gibberellins are applied to dwarf Maize, Pisum & Vicia faba, then they become tall. The rosette plant of sugarbeet indicate an extreme dwarfism, this habit can be eliminated by GA.
- **Parthenocarpy** : Like auxin, exogenous use of GA also induces the formation of seedless fruits.
- **Substitution of cold treatment or vernalisation** : In many plants low temperature (0–10°C) is essential for flowering. They form vegetative body in the first year and reproductive growth in the second year (for low temperature). But GA overcomes the requirement of low temperature and flowering can be done in the first year.
- **Breaking of dormancy** : GA breaks the dormancy of seeds, buds and rhizomes.
- **Seed germination** : Gibberellin induces the synthesis of hydrolysing enzymes like α-amylase, lipases & proteases. Thus it helps in seed germination.
- **Sex expression** : GA induces maleness in Cucumis, Cannabis etc.
- **Germination of photoblastic seeds** : Gibberellin treated light sensitive seeds can germinate in dark. E.g. Lettuce, Tobacco.
- **In fermentation** : More growth of yeast cells by GA.
- **Increase height of sugarcane plant** : Increase of sugar contents by IAA.

BIO-ASSAY

- **Synthesis of α-amylase and proteases in germinating grains of cereals** : Gibberellins also stimulate the synthesis of α-amylase and protease enzymes which are involved in the conversion of starch into sugar. The gibberellin produced in the embryo moves to the layer of aleurone granules where it stimulates the synthesis of α-amylase and protease enzymes. Protease converts an inactive β-amylase to the active form. The active β-amylase and α-amylase together digest starch to glucose which is mobilized to meet the metabolic demands of the embryo.
- **Dwarf pea and Maize test** : Seeds of dwarf pea are allowed to germinate till just the emergence of plumule. GA solution is applied to some seedlings, others are kept as control. After 5 days, epicotyl length is measured. Increase in length of epicotyl over control seedlings is proportional to GA concentration.

Phosphon-D, Cycocel, Amo-1618, Alar-85, Ancymidol (A-REST) are **anti-gibberellins** and cause inhibition of stem growth.

CYTOKININS (CK)

- Cytokinin was discovered by **Miller** when he was working in the lab. of **Prof. Skoog** on tobacco pith culture. He added the contents of an old DNA-bottle (**Herring fish sperm DNA**) to the culture medium & observed that the tobacco pith callus could grow for a longer period.
- Miller isolated an active substance from autoclaved Herring sperm DNA, which stimulated cell division. He named this substance as **kinetin**.
- The first natural cytokinin was identified and crystallized from immature corn grains by **Letham** and named as **zeatin**.
- The most common cytokinin in plants are zeatin and isopentenyl adenine.
- Cytokinin is a derivative of adenine base.
- Root tips are major site of synthesis of cytokinin (by Mevalonic acid pathway).
- Movement of cytokinin is **polar** & **basipetal**.
- Coconut milk also performs activity like cytokinin, and is, thus, used in tissue culture.
- Benzylamino purine (BAP), Diphenylurea and Thidiazuron are **synthetic cytokinins**.

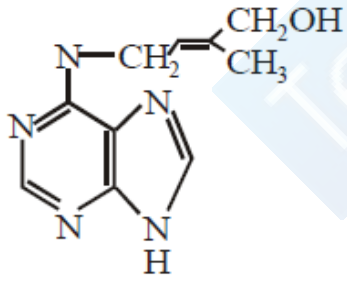


Fig. : Zeatin 6-(4 hydroxy-3methyl-trans-2-butenylamino purine

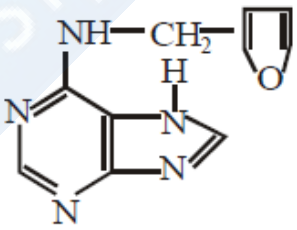


Fig. : Kinetin (N^6-furfuryl aminopurine)

PHYSIOLOGICAL EFFECTS AND ITS APPLICATIONS

- **Cell division (Characteristics function of cytokinin) & Cell enlargement** : One of the most important biological effects of CK (cytokinin) on plants is the induction of cell division. This has been established in roots, anthers and in callus tissue.
- Formation of interfascicular cambium causes induction secondary growth.
- **Morphogenesis** : Morphogenetic changes induced by CK in presence of IAA.

$$\left[\frac{\text{Low CK}}{\text{High Auxin}} \rightarrow \text{root formation}\right]$$

$$\left[\frac{\text{High CK}}{\text{Low Auxin}} \rightarrow \text{shoot differentiation}\right]$$

$$\left[\frac{\text{Cytokinin}}{\text{Intermediate auxin}} \rightarrow \text{Roots as well as shoots formation}\right]$$

$$\left[\frac{\text{Intermediate cytokinin}}{\text{low auxin}} \rightarrow \text{Growth of large amount of callus}\right]$$

- **Counteraction of apical dominance** : Promotes growth of lateral buds.
- **Breaking the dormancy of seeds** : Like GA, the dormancy of certain seeds can be broken by CK.
- **Seed germination** : Seeds of parasite plant (Striga) can germinate in the absence of host by CK treatment.
- **Delay in senescence (Richmond Lang effect)** : The ageing process of leaves is usually accompanied with the loss of chlorophyll and rapid catabolism. This is called as **senescence**. Senescence can be postponed by CK (increase in short life of plant parts).
- Lignin biosynthesis.
- Parthenocarpy in some fruits.
- Cytokinin stimulates the conversion of immature plastids into functional chloroplasts.
- **Phloem conduction** : stimulates mobilisation of nutrients.
- **Sex expression** : Cytokinins causes femaleness in plants.
- Flowering in SDP (also in some long day plants).
- Induces stomatal opening.

BIO-ASSAY

- **Tobacco pith cell division test** : Tobacco pith culture is divided into two weighted lots. One is supplied with cytokinin and the other is kept without it. After 3-5 weeks, increase of fresh weight of treated tissue over control is noted. It is a measure of stimulation of cell division and hence cytokinin activity.
- **Chlorophyll preservation (retention) test** : Leaves are cut into equal sized discs with the help of a cutter. They are divided into two lots. One lot is provided with cytokinin. After 48-72 hours, leaf discs are compared for chlorophyll contents. Cytokinin retards chlorophyll degradation.
- **Soyabean and radish cotyledons cell division test** : Excised cotyledons are measured and placed in test solution as well as ordinary water (as control). Enlargement of cotyledons indicates cytokinin activity.

ABSCISIC ACID (ABA $C_{15}H_{20}O_4$)

- During mid-1960s, three independent researches reported the purification and chemical characterisation of three different kinds of inhibitors : inhibitor-B, abscission II and dormin. Later all the three were proven to be chemically identical. It was named as abscisic acid (ABA).
- Addicott and Okhuma (1963) obtained a substance from mature cotton fruits and named it as abscisin. ($C_{15}H_{20}O_4$)
- Warieng and Robinson isolated a growth inhibitor from old betula leaves and called it as **dormin**.
- ABA is synthesized in old leaves, fruits and old parts by mevalonic acid pathway and oxidation of carotenes in chloroplasts.

- ABA is also known as the stress **hormone** because it protects plants from adverse conditions like water stress. ABA increases tolerance of plants to various type of stresses.
- ABA is the most widespread growth inhibitor in the plants.

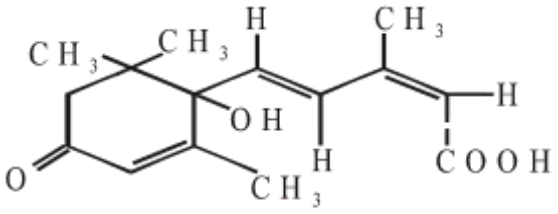


Fig. : Abscisic acid

PHYSIOLOGICAL EFFECTS AND ITS APPLICATIONS

- **Induce abscission** : ABA causes ageing and abscission of leaves & fruits (anti-auxin) (cellulase and pectinase genes induced by ABA detach old parts from the mother plant).
- **Induce bud and seed dormancy** : ABA regulates (anti-GA) bud and seed dormancy.
- **Induce senescence** : ABA accelerates senescence of leaves.
- **Inhibition of cell division and cell elongation**. It is working against cytokinin and auxin (anti-CK and anti-auxin).
- **Stomatal closing** : ABA accumulates in high concentration in leaves which are wilting. This increased production of ABA stimulates stomatal closure by inhibiting the K^+ uptake by guard cell and promoting the leakage of malic acid and hence prevents transpiration.
- Delaying of flowering in LDP
- **Seed development** : Abscisic plays major role in seed development and maturation, enabling seeds to withstand desiccation and to become dormant.
- **Inhibitor of seed germination** : ABA is an inhibitor of synthesis of α-amylase. Thus, it inhibits the germination of seeds.
- Geotropism in roots
- Growth inhibition in Duckweed (Lemna)

BIO-ASSAY

- **Rice seedling growth inhibition test** : Mohanty, Anjaneyulu and Sridhar (1979) used rice growth inhibition method to measure ABA like activity. The length of second leaf sheath after six days of growth is measured.
- **Inhibition of α-amylase synthesis in barley endosperm test** : ABA inhibits the synthesis of α-amylase in the aleurone layers which is triggered by gibberellins. Goldschmidt and Monselise (1968) developed the bioassay method to estimate ABA activity by determining the extent of inhibition of α-amylase synthesis induced by treating barley seed endosperm with GA.

ETHYLENE

- Cousins confirmed the release of a volatile substance from ripened oranges that hastened the ripening of stored unripened bananas. Later, this volatile substance was identified as ethylene, a gaseous plant growth regulator.
- Biosynthesis of ethylene takes place by methionine amino acid. Ethylene is synthesized in large quantities by ripening fruits and senescent organs.
- Ethylene is also formed in roots in waterlogged condition.

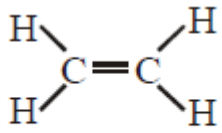


Fig. : Structure of ethylene

PHYSIOLOGICAL EFFECTS AND ITS APPLICATIONS

- **Triple response** : Ethylene inhibits elongation of stem, causes swelling of nodes and nullifies geotropism.
- **Flowering** : Like auxins, ethylene retards flowering in most plants but increases flowering in pineapple like auxins.
- **Sex modification** : Ethylene increases the number of female flowers and reduces the number of male flowers.
- **Abscission** : Ethylene causes faster abscission of leaves and flowers.
- **Fruit ripening** : Ethylene is a ripening agent. Ethylene is formed in large quantities in ripening fruits.
- Fruits that respond to ethylene usually have a major increase in respiration just before ripening occurs. The increase in ethylene production at that time is often up to 100 times greater than the normal. The accompanying major increase in respiration is called **climacteric** and fruits that exhibit such phenomena are called **climacteric fruits** e.g. apple, banana, mango, tomato etc. Some fruits such as grapes, pineapple, water-melon are **non-climacteric** and do not respond in such a way to ethylene.
- **Ethephon** : 2-chloroethyl phosphonic acid is a liquid from which ethylene gas released gradually, hence this substance is used for artificial ripening of fruits. Fruits so ripened are similar to normally ripened fruits, in colour and shape etc.

BIO-ASSAY

- **Triple pea test** : Pratt and Biale (1944) developed this method for bioassay of ethylene which is based on the physiological effect of ethylene to cause –
  - Subapical thickening of stem
  - Reduction in the rate of elongation
  - Horizontal nutation (transverse geotropism) of stem in etiolated pea seedlings. In the presence of ethylene, epicotyls show increased growth in thickness and reduced rate of longitudinal and horizontal growth.
- **Pea stem swelling test** : Cherry (1973) used pea seedlings to measure ethylene concentration by marked increase of stem swelling expressed as a ratio of weight to length.

PHOTOPERIODISM

- First of all **Garner and Allard** studied the "Effect of requirement of relative length of day (**photoperiod)** and night (dark phase) on flowering of plants and this process is known as **photoperiodism**".
- They experimented on a mutant variety of tobacco and soybean.
- **Critical period** : Critical photoperiod is that continuous duration of light, which must not be exceeded in short day plants and should always be exceeded in long day plants in order to bring them to flower.
- The plants are classified into three groups according to their photoperiods viz., **long-day plants**, **short-day plants** and **day-neutral plants**.

SDP (SHORT DAY PLANTS)

These plants flower on exposure to photoperiod equal to or shorter than their critical day length. They need a continuous (uninterrupted) dark period of flowering. Thus, SDP is appropriate to called as long night plants.

In SDP, the dark period is critical and must be continuous. If this dark period is interrupted even with a brief exposure of red light, the SDP will not flowers.

E.g. of SDP : Tobacco, Soyabean, Viola, Xanthium (Cocklebur), Chrysanthemum, Cannabis, Coleus, Chenopodium, Mustard, Dahlia, Sugarcane, Strawberry, Cosmos, Rice etc.

LDP (LONG DAY PLANTS SHORT NIGHT PLANTS)

These plants flowers only when they exposed to critical photoperiod or photoperiod longer than their critical day length.

In LDP, flowering is not done if photoperiod is less than the critical period and a brief exposure in the dark period stimulates flowering in LDP. The light period is critical for LDP.

E.g. Henbane (Hyoscyamus), Spinach, Sugarbeet, Radish, Carrot, Wheat, Larkspur, Barley, Avena, Potato.

DNP (DAY NEUTRAL PLANTS) OR INTERMEDIATE PLANTS

These plants do not need a specific light period for flowering.

E.g. Maize, Cotton, Tomato, Sunflower, Cucumber.

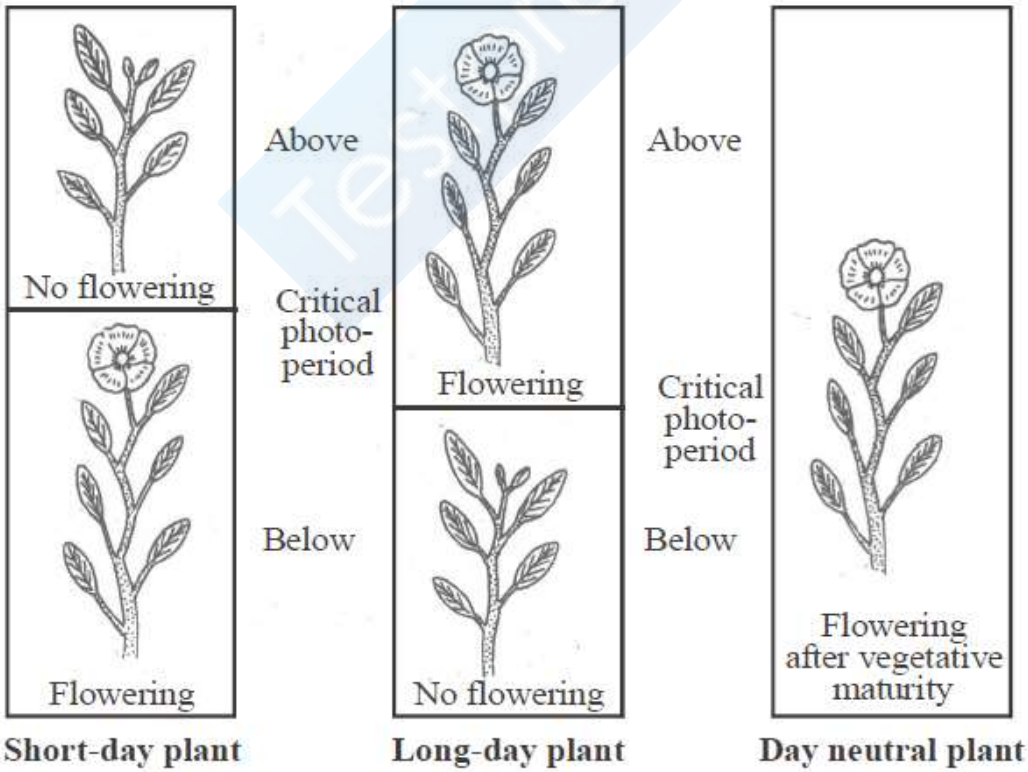


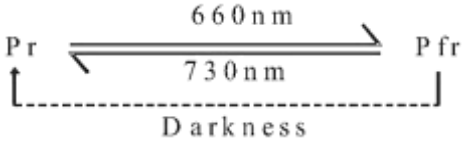
Fig. : Three major types of photoperiodic behaviour for flowering

PHYTOCHROME

- **Borthwick and Hendrics** discovered a light sensitive pigment responsible for flowering.
- Butler isolated and gave the term "phytochrome" for this pigment.
- Phytochrome is mainly localised on cell membrane of all types of plants.
- Phytochrome exists in two inter-convertible phases.

○ **Pr (phytochrome red) or P_{660} phase** : Red light absorbing form, induce flowering in SDP. Absorption Range is 630-670 nm. Absorption peak at 667 nm.

○ **Pfr (phytochrome Far Red) or P_{730} phase** : This is far-red light absorbing form, which induces flowering in LDP and then converts into Pr form. Absorption Range is 720-740 nm. Absorption peak is at 735 nm. The Pfr (Yellowish) form, gradually changed into Pr (Bluish) form in dark.



- During the day, the Pfr form is accumulated in the plants which is inhibitory to flowering in SDP but stimulates flowering in LDP.
- **Phytochrome** - Pfr (P_{730}) is the active form which controls many photos physiological processes (e.g. seed germination) in plants.
- Control of morphogenesis by light & phytochrome is called **photomorphogenesis**.
- Photomorphogenesis in higher plants appears to be under control of one of three photoreceptors:

○ **Phytochrome** - which absorbs red and far red region of light.

○ **Cryptochrome** - which absorbs blue and UV-A (approx. 380nm) light.

○ **UV-B photo-receptor** - which absorbs UV-B (approx. 290 nm) light.

VERNALISATION

- **Vernalization** is the low temperature treatment given to water soaked seeds, slightly germinated seeds or seedlings to hasten the time of flowering of plants that will develop from them.
- **Chourad** defined it as "acceleration of ability to produce flower by chilling treatment (1°-10°C) is called vernalisation".
- Some important food plants, wheat, barley, rye have two kinds of varieties: winter and spring varieties. The '**spring**' variety are planted in the spring and come to flower and produce grain before the end of the growing season. **Winter** varieties, however, if planted in spring would normally fail to flower or produce mature grains within the span of a flowering season. Hence, they are planted in autumn (September to October). They germinate, and over winter come out as small seedlings, resume growth in the spring and are harvested usually around mid-summer.
- Vernalization is also seen in biennial plants. Biennials are monocarpic plants that normally flower and die in the second season. Sugarbeet, cabbages, carrots are some of the common biennials. Subjecting the growing of biennial plants to a cold treatment stimulates a subsequent photoperiodic flowering response.

REQUIREMENT OF VERNALIZATION

- **Low temperature** : Low temperature required for vernalization is usually 0-4°C in most of the cases. The chilling treatment should not be immediately followed by high temperature (i.e., about 40°C), otherwise the effect of vernalization is lost. This phenomenon is called de-vernalization.
- **Duration of low temperature treatment** : It varies from species to species from a few hours to a few days.
- **Actively dividing cells** : Vernalization stimulus is perceived only by actively dividing cells, e.g., embryo tip, shoot apex and leaves. Therefore, vernalization treatment can be given to the germinating seeds or whole plant with meristematic tissues and other conditions.

- **Water** : Proper hydration is a must for perceiving the stimulus of vernalization.
- **Oxygen** : Aerobic respiration is also a requirement for vernalization. The stimulus has been named as vernalin (reported by Melchess, 1936-37).

SIGNIFICANCE OF VERNALISATION

- Vernalisation shortens the vegetative period of the plant.
- It increases the cold resistance of the plants.

SEED GERMINATION

When a seed of plant provides suitable conditions, various changes take place by which a seedling comes from seed and germinates, this is called germination of seeds. There is a requirement of water, oxygen and heat for the **germination of seeds**. There are various conditional factors inside the seed like food, hormones etc. for their germination.

The germination of seed takes place by following processes :

- **Hypogeal germination** : At the time of seed germination cotyledons remain below the soil and micropyle absorbs the water by which integument breaks and radicle comes outside through micropyle by breaking the coleorhiza, root forms and shoot forms through plumule. This process of seed germination is known as hypogeal germination. E.g. pea, gram, maize, Cycas etc.
- **Epigeal germination** : At the time of seed germination colytedons come outside from soil and seeds are fixed at the soil through secondary roots. This type of germination is called epigeal germination. E.g. pumpkin (Cucurbita maxima).
- **Vivipary** : Viviparity is a unique adaptation in mangrove plants. Usually seeds require oxygen for germination. Oxygen is present in less amount in saline water. So, seeds germinate inside the fruit on the mother plant. This feature is called vivipary.

SEED DORMANCY

Dormancy may be defined as the inactive state of the seed in which the growth of the embryo is temporarily suspended for a specific length of time.

Many viable seeds germinate immediately after harvest if provided with suitable conditions of germination, i.e., water, oxygen and a suitable temperature (some seeds, e.g., lettuce need light also). However, perfectly viable seeds of many plants do not germinate immediately after harvest even when provided with suitable conditions of germination, i.e., their germination is blocked. This is called dormancy.

Seed dormancy may be due to many causes, such as external environment, endogenous control or conditions within seed itself some of which are as follows :

- **Impermeability of seed coats to oxygen**, e.g., Xanthium.
- **Impermeability of seed coats to water,** e.g., many plants of legumes.
- **Hard seed coat**, which does not allow proper growth of developing embryo, e.g., mustard.

- **Immature embryo** : Some seeds contain an imperfectly developed embryo.
- **Embryo requiring after-ripening in dry storage** : These embryos although fully developed, do not germinate unless kept in storage in a dry place for sometime after harvest, e.g. Crataegus.
- **Germination inhibitors** : Some plants produce such chemical compounds that inhibit the germination of their own seeds, e.g., tomato.
- Other chemical inhibitors are abscisic acid, phenolic acid, para-ascorbic acid, etc.

METHODS OF BREAKING DORMANCY

- **Mechanical scarification** : Weakening of hard seed coat with anything of sharp edge, e.g., pieces of glass, knives, sandpaper or vigorous shaking.
- **Chemical scarification** : Treating the seeds with dilute acids, fat solvents, etc. Dormancy can be broken by treating the seeds with strong acids (N_2SO_4) or dipping in boiling water or rubbing on a rough surface.
- **High temperature treatment** : Permeability of seed coat in alfa-alfa seeds increases when they are kept in water at the temp. of 85-90° for some time.
- **To neutralize the effect of inhibitors** : Effect of germination inhibitors on the seeds can be counteracted by giving low and high temperature treatments to seeds or by treating the seeds with KNO_3, thiourea, gibberellin, ethylene, chlorohydrin, etc.

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