Plant Growth and Development - Part 2

Objectives

After going through this lesson, the learners will be able to understand the following:

- Plant Growth Regulators
- The Discovery of Plant Growth Regulators
- Physiological Effects of Plant Growth Regulators

Content Outlines

- Plant Growth Regulators
  - Characteristics
  - The Discovery of Plant Growth Regulators
  - Physiological Effects of Plant Growth Regulators

Plant Growth Regulators

Characteristics

The plant growth regulators (PGRs) are small, simple organic molecules of diverse chemical composition. They are also known as phytohormone as they fulfil the three criteria of hormones namely 1) they can work at very low concentration in plants, 2) they get translocated from their site of synthesis to various other regions of plants for action, 3) they promote or regulate growth and development related activities in plants. Major phytohormones can be tryptophan derived indole compounds (indole-3-acetic acid, IAA); derivatives of adenine (N6-furfurylamino purine, kinetin), derivatives of carotenoids (Abscisic acid, ABA); terpenes (Gibberellic acid,GA3) or gases (Ethylene, C_2H_4).

Based on their physiological roles in plants the PGRs can be broadly divided into two groups–

- **Growth promoters:** those which are involved in growth promoting activities, such as cell division, cell enlargement, pattern formation, tropic growth, flowering, fruiting and seed germination and seedling growth, e.g., Auxins, Gibberellins and Cytokinins.
- **Growth regulators/stress hormones:** those which are involved in responses wounds and stresses of biotic and abiotic origin. They are also involved in various growth inhibiting activities such as dormancy and abscission, e.g., gaseous PGR, ethylene and Abscisic acid.

The Discovery of Plant Growth Regulators

Auxin: It was the first PGRs to be discovered. First observation was made by Charles Darwin and his son Francis Darwin when they observed that the coleoptiles of canary grass responded to unilateral illumination by growing towards the light source (phototropism). After a series of experiments,it was concluded that the tip of coleoptile was the site of transmittable influence that caused the bending of the entire coleoptile (Figure 15.10). Auxin was isolated, chemically characterized and named by F.W. Went from tips of coleoptiles of oat seedlings (Fig. 15.8).

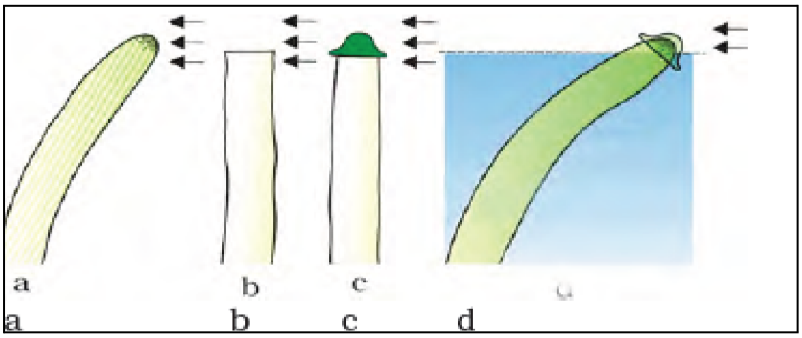


Figure 15.8: Experiment used to demonstrate that tip of coleoptile is the source of auxin indicate direction of light

Gibberellins: E. Kurosawa (1926) reported that when sterile filtrates of the fungal pathogen *Gibberella fujikuroi* was applied on rice seedling it resulted in 'bakanae' (foolish seedling) disease where plants grow extraordinarily. The active substances were later identified as gibberellic acid.

Cytokinins: F. Skoog and his co-workers observed that tissue taken from tobacco stem pith resulted in callus (a mass of undifferentiated parenchymatous cells) only if they are cultured in a medium containing auxins supplemented with any one of the following: extracts of vascular tissues, yeast extract, coconut milk or aged DNA. F. Skoog and C.O. Miller, later identified and crystallised the first cytokinesis promoting active substance from an old stock of Herring sperm DNA and they termed it kinetin. First cytokinin from the plant source was isolated from Zea mays kernels by Litham and was named Zeatin.

Abscisic acid: During mid-1960s, three independent researchers isolated, purified and chemical characterised three different kinds of Inhibitory compounds in plants: inhibitor-B (Avena coleoptile), abscission II (cotton /lupin seeds) and dormin (leaf buds of perennial plants). Later all the three were proved to be chemically identical and in order to avoid confusion they all were given a common name abscisic acid (ABA).

Ethylene: In 1901 a Russian physiologist Dimitry N. Neljubow identified that ethylene present in illuminating street light gas can cause triple response in pea seedling: inhibited stm elongation, increased stem thickening and a horizontal growth habit. In 1910, H. H Cousins observed the release of a volatile substance from ripened oranges that enhanced the ripening of un ripened bananas stored along. Later this volatile substance was identified as ethylene, a gaseous PGR.

Let us study some of the physiological effects of these five categories of PGRs in the next section.

Physiological Effects of Plant Growth Regulators

Auxins

The term Auxins was coined by F.W. Went (from Greek word 'auxein': to grow) and was first isolated from human urine. 'Auxin' is commonly applied to all natural, and synthetic compounds having certain growth regulating properties. They are generally produced by the growing apices of the stems and roots, from where they are transported to various regions of plants for their action. Auxins show polar transport in acropetal or basipetal manner from their site of synthesis to site of action. Auxins like Indole 3-acetic acid (IAA) and Indole butyric acid (IBA) have been isolated from plants whereas NAA (naphthalene acetic acid) and 2, 4-D (2, 4-dichlorophenoxyacetic) are synthetic auxins. All these auxins have been extensively used in agricultural and horticultural practices. NAA in the form of commercial rooting mixture helps to initiate rooting in stem cuttings and is widely used for plant propagation. Spraying of auxins like NAA and IBA promote flowering e.g., in pineapples. They help to prevent fruit and leaf drop at early stages but promote the abscission of older mature leaves and fruits. In most higher plants, the growing apical bud inhibits the growth of the lateral (axillary) buds, a phenomenon called apical dominance which is a result of high concentration of auxin in the apical region. Removal of apical bud (decapitation/ pruning) usually results in profuse growth of lateral buds (Figure 15.9). Pruning is widely applied in tea plantations, hedge-making. Can you explain why? Auxins also induce parthenocarpy, e.g., in tomatoes. 2, 4-D, is widely used as weedicide and it selectively kills broad-leaved dicotyledonous weeds, without affecting mature monocotyledonous plants. It is therefore used to prepare weed-free lawns by gardeners. Auxin is responsible for phototropic and geotropic movements in plants. Auxin also controls xylem differentiation and helps in cell division. It also helps in growth by cell enlargement in intact and excised plant tissues.

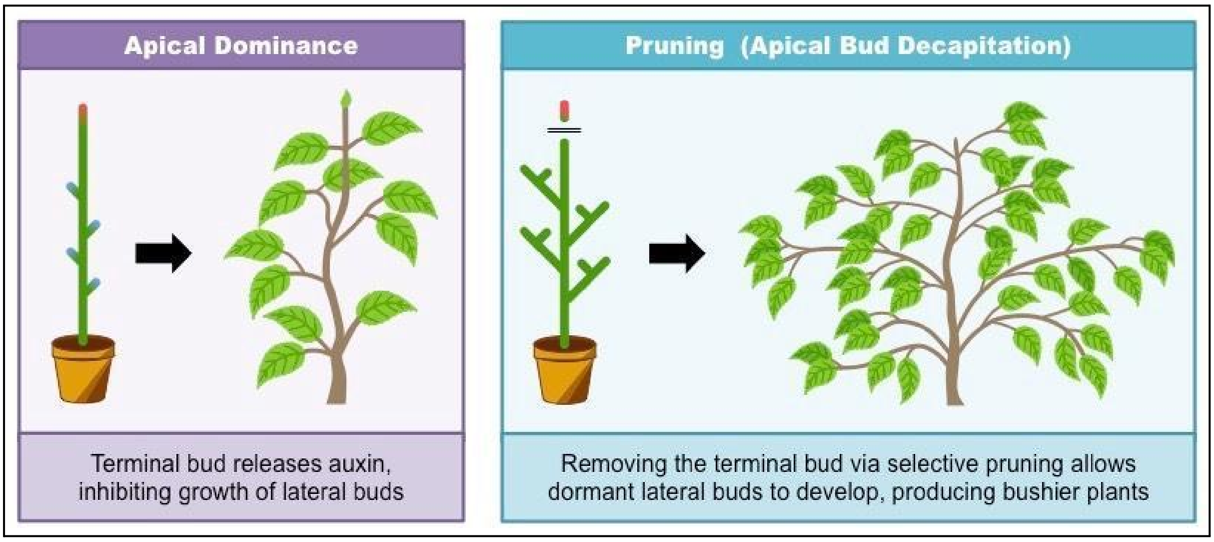


Figure 15.9: Role of Auxin in apical dominance and inhibition of lateral bud growth

Gibberellins

Gibberellins are another type of growth promoting compound. There are more than 100 gibberellins reported from widely different organisms such as fungi and higher plants. They are denoted as GA1, GA2, GA3 and so on. Gibberellins differ in having either C19 or C20 structure. Gibberellic acid (GA3) was one of the first gibberellins to be discovered and the most intensively studied form. All GAs are acidic and are present in germinating seeds, young embryos, leaf buds. They are transported along phloem and xylem transport. They produce a wide range of physiological responses in the plants. Their ability to cause an increase in internode length of intact plants and this property is practically utilised in sugarcane to increase stem length without compromising on sucrose content thus increasing the yield by as much as 20 tonnes per acre. They hydrolyses stored starch in sugars in hydrated germinating seeds thereby helping in seed germination. Gibberellins increase alpha amylase activity therefore they are widely used in the malt industry. They causes fruits like apple to elongate and improve their shape. Spraying juvenile conifers with GAs hastens the maturity period, thus leading to early seed production. Gibberellins also promote bolting (internode elongation just prior to flowering) in beet, cabbages and many plants with rosette habit(Fig 15.10). Anti Gibberellins are compounds having antagonistic effects to gibberellins. They block biosynthesis of gibberellins in plants thereby making plants dwarf. Anti Gibberellins are commonly used in horticulture to give a bushy look to ornamental plants like Chrysanthemum. Besides this they are used in certain crops like wheat to raise dwarf varieties which are resistant to lodging. Anti Gibberellins like BX-116 are naturally occurring in plants whereas AMO 1618, CCC, Acrymidol and Phosphon D are some synthetic anti giberellins.

A B

Figure 15.10: A- Rosette plant, B- Bolted plant (during flowering)

Cytokinins

Cytokinins have specific effects on cytokinesis, and were discovered as kinetin (a modified form of adenine, a purine) from the autoclaved herring sperm DNA. Kinetin does not occur naturally in plants. Search for natural substances with cytokinin-like activities led to the isolation of zeatin from corn-kernels and coconut milk. Since the discovery of zeatin, several naturally occurring cytokinins, and some synthetic compounds with cell division promoting activity, have been identified. Cytokinins are of two types: aliphatic (iP, Zeatin and Dihydrozeatin) and aromatic (Benzyl adenopurine). Natural cytokinins are synthesised in meristematic regions where rapid cell division occurs, for example, root apices, developing shoot buds, young fruits etc. It has several physiological roles to play in plants, helps in delaying senescence but preventing chlorophyll degradation (Richmand-Lang effect), Induce cell division in invitro plant cultures. Helps in shoot formation in tissue culture explants and callus. By altering the ratio of auxin and cytokinins in tissue culture, medium root / shoot induction can be regulated (Fig 15.11). Cytokinin plays an important role in preventing apical dominance by suppressing the growth of apical bud and allowing lateral buds to grow profusely. They also help in maintaining apical meristems in plants and adventitious shoot formation. Cytokinins are called sink hormones since they promote nutrient mobilisation to the site where the hormone is synthesised.

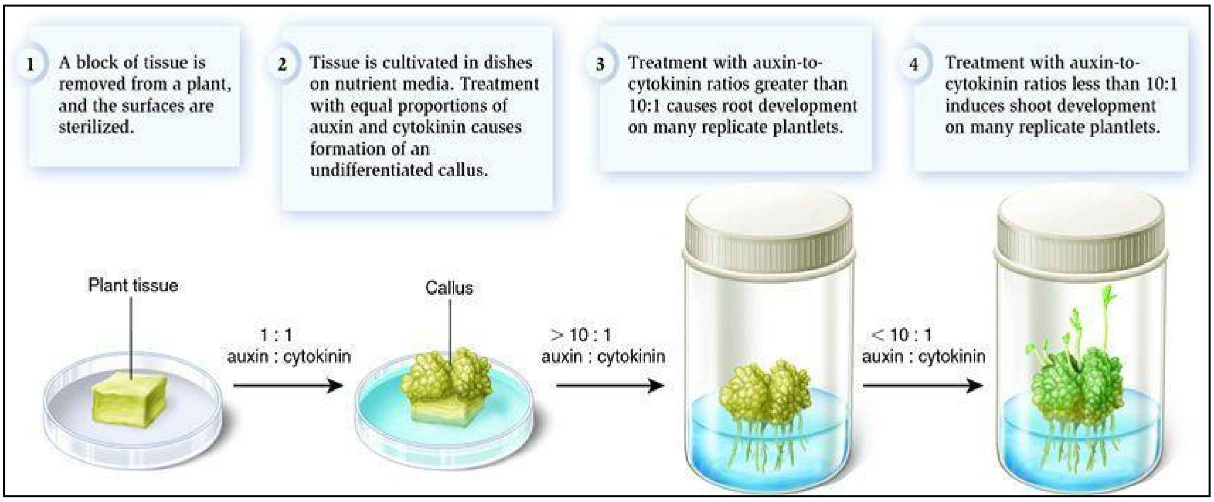
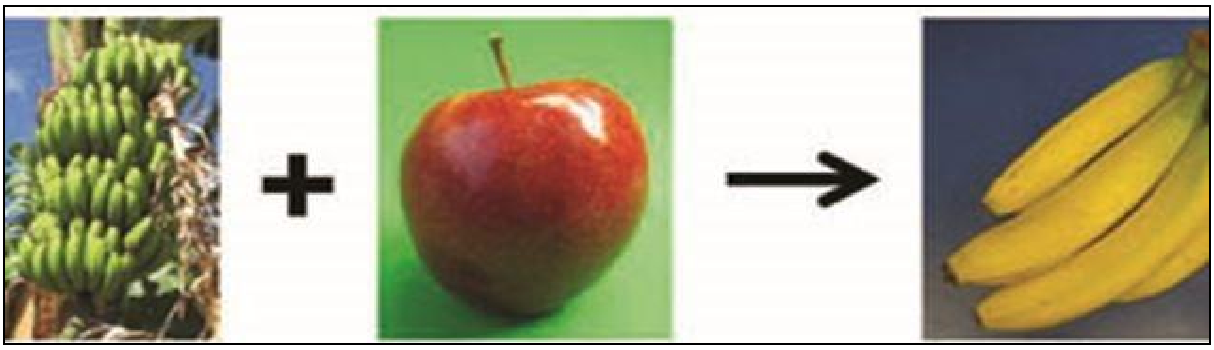


Figure 15.11: Role of Auxin and Cytokinin in root/shoot differentiation in tissue culture explant

Ethylene

Ethylene is a simple gaseous plant hormone. It is synthesised in large amounts by tissues undergoing senescence and ripening fruits and therefore it is also called fruit ripening hormone. It is basically produced under stress conditions and therefore does not promote growth related activity. Many physiological responses shown by auxins are overlapping with ethylene since they are observed due to auxin induced ethylene production. Influences of ethylene on plants include horizontal growth of seedlings, swelling of the axis and apical hook formation in dicot seedlings. Ethylene promotes senescence and abscission of plant organs especially of leaves and flowers. Ethylene is highly effective in fruit ripening. It enhances the respiration rate during ripening of the fruits (Fig 15.4.5). This rise in the rate of respiration is called respiratory climactic. Fruit ripening is a complex process since it involves many morphological, physiological and biochemical changes in fruits like softening of fruit walls, change in wall pigmentation, and fruits becoming sweet due to hydrolysis of starch into sugar. Change in fruit colour. Ethylene breaks seed and bud dormancy, initiates germination in peanut seeds, sprouting of potato tubers. Ethylene promotes rapid internode/petiole elongation in deep water rice plants or in waterlogged conditions. It helps in more growth on the upper surface of the leaf (epinasty) so that it remains above water in aquatic plants. Ethylene also promotes lateral root growth and root hair formation, thus helping the plants to increase their absorption surface. Ethylene is used to initiate flowering and for synchronising fruit-set in pineapples. It also induces flowering in mango. It also controls geotropic movements in plants. Since ethylene regulates so many physiological processes, it is one of the most widely used PGR in agriculture. The most widely used compound as source of ethylene is ethephon/ethrel. Ethephon in an aqueous solution gets broken down to ethylene, phosphoric acid and chloride ions. It is readily absorbed and transported within the plant and releases ethylene slowly. Ethephon hastens fruit ripening in tomatoes and apples (Fig. 15.12) and accelerates abscission in flowers and fruits (thinning of cotton, cherry, walnut). It promotes female flowers in cucumbers thereby increasing the yield.



A B C

Figure 15.12: A- unripe banana, B- Ripe apple as a source of ethylene, C – Banana ripened

Abscisic acid

As mentioned earlier, abscisic acid (ABA) was discovered for its role in regulating abscission and dormancy. Abscisic acid is derived from carotene through a 40 Carbon intermediate called violaxanthin. Abscisic biosynthesis occurs in the chloroplast and cytoplasm of a cell. Just like other PGRs, it also has other wide ranging effects on plant growth and development but it acts as a general plant growth inhibitor and an inhibitor of plant metabolism. ABA inhibits seed germination. ABA stimulates the closure of stomata in case of water stress and increases the tolerance of plants to various kinds of stresses, therefore, it is also called the stress hormone (Fig 15.13). ABA plays an important role in seed development, maturation and dormancy and therefore decreased levels of ABA in plants result in vivipary (Fig. 15.14) (precocious germination of seed within the fruit). By inducing dormancy, ABA helps seeds to withstand desiccation and other factors unfavourable for growth. In most situations, ABA acts antagonist to GAs. We may summarise that for any and every phase of growth, differentiation and development of plants, one or the other PGR has some role to play. Such roles could be complimentary or antagonistic. These could be individualistic or synergistic.

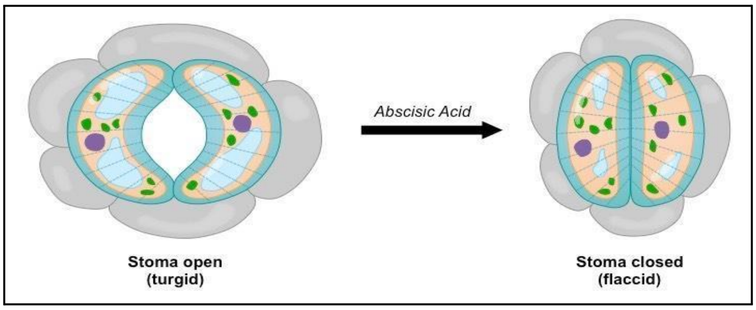


Figure 15.13: Effect of ABA in stomatal guard cell movement

Figure 15.14: Maize mutant for ABA showing precocious germination of seeds in the cob

Similarly, there are a number of events in the life of a plant where more than one PGR interact to affect that event, e.g., dormancy in seeds/buds, abscission, senescence, apical dominance, etc. Remember, the role of PGR is of only one kind of intrinsic control. Along with genomic control and extrinsic factors, they play an important role in plant growth and development. Many of the extrinsic factors such as temperature and light control plant growth and development via PGR. Some of such events could be: vernalisation, flowering, dormancy, seed germination, plant movements, etc.