M4 L1

Cell signalling models and hormones

In this lecture we will study about the various cell signalling models and in the later part about hormones which mediate cell signalling.

Cell Signaling: Secreted molecules mediate via three forms of signaling namely Paracrine, Autocrine, and Endocrine. Signaling molecules that a cell secretes may be carried far afield to act on distant targets, or they may act as local mediators, affecting only cells in the immediate environment of the signaling cell.

1. Autocrine signaling
2. Paracrine signaling
3. Endocrine signaling

1. Autocrine signaling:

In the autocrine signaling, cells respond to substances which they themselves release (as shown in Figure 1(a) and thus changes takes place in the cell itself. A cell secretes a hormone or chemical messenger that stimulates its own growth and proliferation. An example of an autocrine agent is the cytokine interleukin-1 in monocytes. It is produced in response to external stimuli and binds to cell-surface receptors on the same cell that produced it. Autocrine signaling is a characteristic feature of tumor cells, many of which overproduce and release growth factors that stimulate inappropriate, unregulated self-proliferation as well as influencing adjacent non-tumor cells; this process may lead to formation of a tumor mass. In autocrine signaling, a group of identical cells produces a higher concentration of a secreted signal than does a single cell as shown in Figure 1 (b).

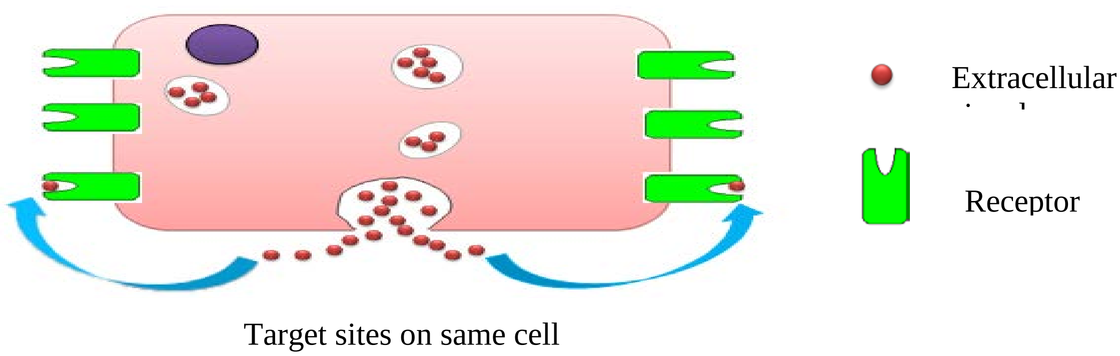


Figure 1 (a): Autocrine signaling: Cells responding to substances which they themselves release.

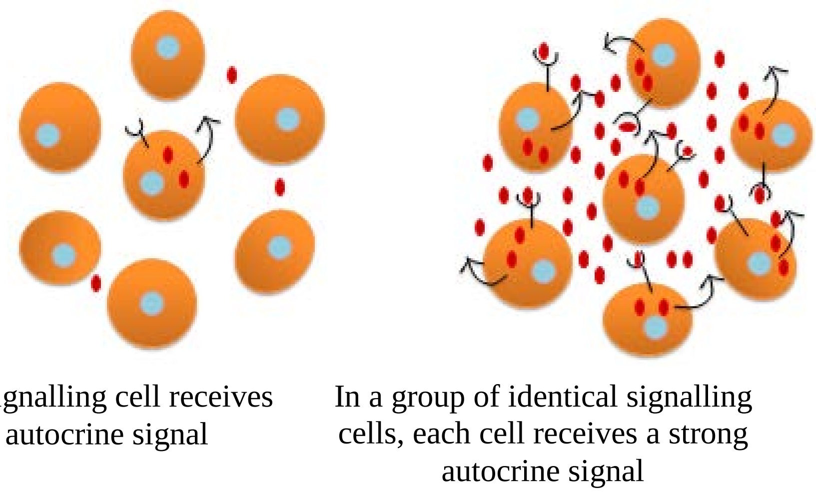


Figure 1 (b): Autocrine signaling A group of identical cells produces a higher concentration of a secreted signal than does a single cell.

2. Paracrine signaling:

In paracrine signaling (para = near), the signaling molecules released by a signal-releasing cell (secretory cell), affect only those target cells in close proximity as shown in Figure 2 (a) & (b). For paracrine signals to be delivered only to their proper targets, the secreted signaling molecules must not be allowed to diffuse too far; for this reason they are often rapidly taken up by neighboring target cells, destroyed by extracellular enzymes, or immobilized by the extracellular matrix. Many growth factors regulating development in multicellular organisms also act at a short range. Some of these molecules bind tightly to the extracellular matrix, unable to signal, but subsequently can be released in an active form. Many developmentally important signals diffuse away from the signaling cell, forming a concentration gradient and inducing different cellular responses depending on the distance of a particular target cell from the site of signal release. The conduction by a neurotransmitter of a signal from one nerve cell to another or from a nerve cell to a muscle cell occurs via paracrine signaling.

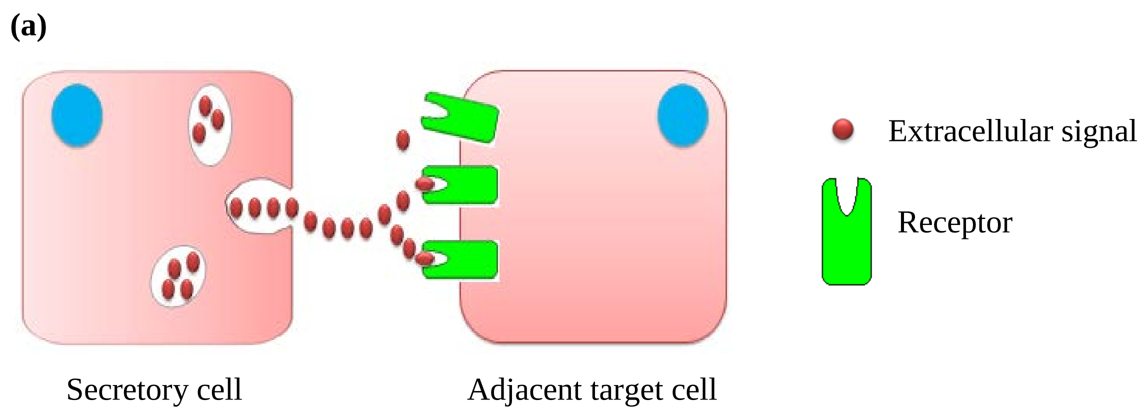


Figure 2 (a): Signaling molecules released by a secretory cell affect only the adjacent target cells.

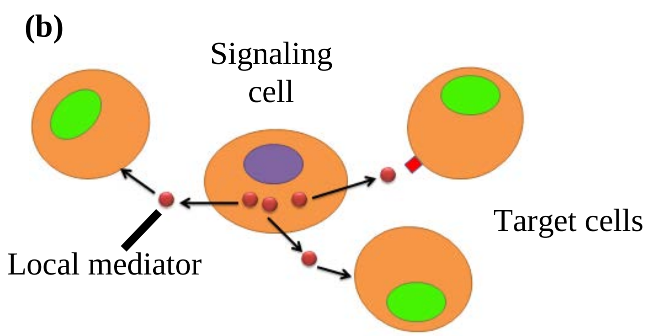


Figure 2 (b): Paracrine signaling: Signaling molecules released by a secretory cell affect only the adjacent target cells in close proximity

3. Endocrine model:

In endocrine signaling, the signaling molecules are synthesized and secreted by endocrine cells, transported through the circulatory system or the tissue fluid of the organism and finally act on target cells distant from their site of synthesis as shown in Figure 3. Endocrine signals are called hormones. The target cells have receptors for binding specific hormones and thereby "pull" the appropriate hormones from the extracellular fluid. Endocrine hormones, for example, insulin and epinephrine, are synthesized and released in the bloodstream by specialized ductless endocrine glands.

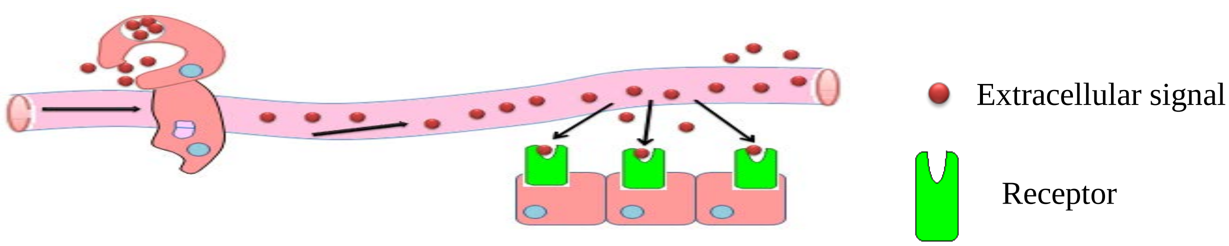


Figure 3: Endocrine signaling: Signaling molecules are synthesized and secreted by endocrine cells, transported through the circulatory system or the tissue fluid of the organism and finally act on target cells distant from their site of synthesis

Hormone: The term hormone is derived from the Greek word ‘horman’ which means ‘to excite’ or ‘to activate’. Hormones are chemical signalling molecules in animals. Endocrine system consists of specialized glands known as endocrine glands which on stimulation secrete powerful chemicals called hormones into the blood stream. The hormones have specific target cells located somewhere else in the body. A **hormone** is a chemical messenger which is released by one or more cells that affects cells in other parts of the organism. It is essentially a chemical that transports a signal from one cell to another. Most hormones initiate a cellular response by initially combining with either a specific intracellular or cell membrane associated receptor protein. A cell may have several different receptors that recognize the same hormone and activate different signal transduction pathways, or alternatively different hormones and their receptors may invoke the same biochemical pathway. For example, insulin is a hormone that is made by the beta cells in the pancreas. When it's released into the blood, insulin helps regulate how the cells of the body use glucose for energy.

Biochemical nature of hormones: Hormones may belong to different biochemical nature. Accordingly, they are classified as:

1. Peptide hormone
2. Steroid hormone
3. Monoamines

1. Peptide hormone: Peptide hormone is a class of peptides which have endocrine functions and is secreted into the blood stream. Peptide hormones are synthesized in cells from amino acids. Numerous significant peptide hormones are secreted from the pituitary gland. Examples of peptide hormones are adrenocorticotrophic hormone (ACTH), growth hormone etc. ACTH is secreted by the anterior pituitary and acts on the adrenal cortex to regulate the secretion of glucocorticoids while growth hormone acts on bone, muscle and the liver.

Peptide hormones cannot pass through the plasma membrane of the cell. So the receptors for these hormones have to be on the plasma membranes of the peptide hormone sensitive cells. When contacted by hormone, these receptors activate a **second messenger** system i.e. a cascade of internal chemical signals that culminate in the secretion of the hormone into the bloodstream. These messengers enter the nucleus and influence gene expression as shown in Figure 4.

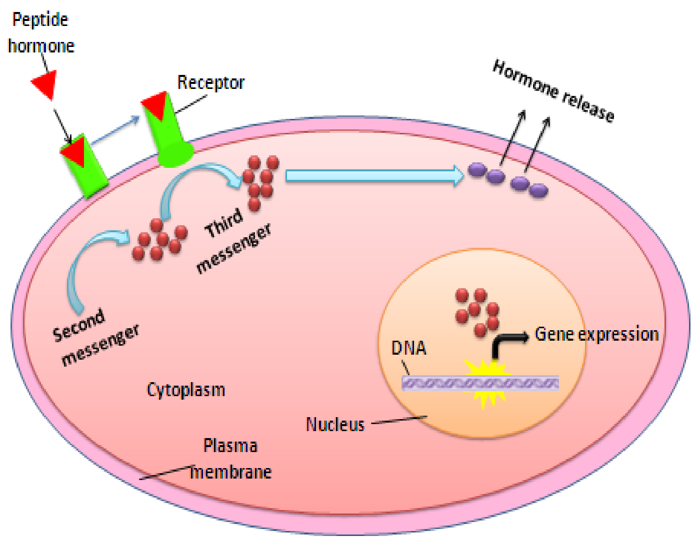


Figure 4: Peptide hormone regulation in vertebrates

2. Steroid hormone: Steroid hormones are derived from cholesterol and eicosanoids. They are lipid soluble. Examples of steroid hormones are testosterone and cortisol. The gonads and the adrenal cortex are the primary sources of steroid hormones. Examples of eicosanoids are prostaglandins.

Steroid hormones being lipid soluble can diffuse through the plasma membrane of the cell very easily. The steroid hormone binds to its receptor in the cytoplasm and the activated hormone-receptor complex enters the nucleus influencing gene expression as shown in Figure 5.

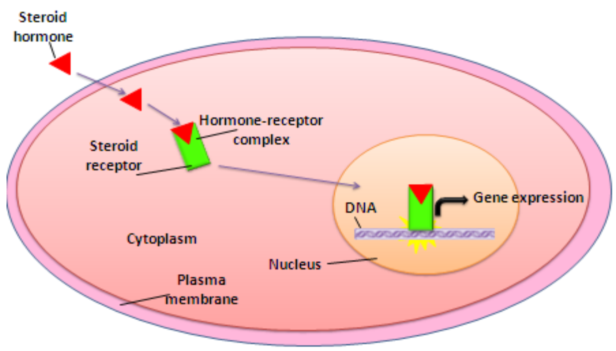


Figure 5: Steroid hormone regulation in vertebrates

3. Monoamines: Monoamines are derived from the aromatic amino acids like tyrosine, tryptophan and phenylalanine by the action of aromatic amino acid decarboxylase enzymes. Examples of monoamines are epinephrine, norepinephrine etc.

Endrocrine system and function: The endocrine system consists of the system of glands. Each gland secretes different types of hormone directly into the bloodstream to regulate the body.

Hormones of the pituitary gland: The pituitary is a small, pea-sized gland situated at the base of the brain. It sends signals to the thyroid and adrenal glands and the ovaries and testes, directing them to produce thyroid hormone, cortisol, estrogen, testosterone, and other hormones. These hormones have an effect on the metabolism, blood pressure, sexuality, reproduction and other essential functions of the body. In humans, the pituitary gland consists of three lobes:

- Anterior Lobe (Adenohypophysis)
- Posterior Lobe (Neurohypophysis)
- Intermediate lobe

1. Anterior Lobe: The anterior lobe contains six types of secretory cells. All of them secrete their hormone in response to hormones reaching them from the hypothalamus of the brain.The anterior pituitary gland secretes the following vital endocrine hormones:

(a) Thyroid stimulating hormone (TSH): Thyroid-stimulating hormone (thyrotropin) is a glycoprotein consisting of an alpha chain of 92 amino acids and a beta chain of 118 amino acids. TSH is synthesized and secreted by thyrotrope cells in the anterior pituitary gland. Thyroid stimulating hormone stimulates the thyroid gland to secrete the hormone thyroxine (T_4). T_4 is converted to triiodothyronine (T_3), which is the active hormone that stimulates metabolism. The TSH receptor is found mainly on thyroid follicular cells. A deficiency of TSH causes hypothyroidism. TSH deficiency has also been implicated as a cause of osteoporosis.

(b) Follicle-Stimulating Hormone (FSH): FSH is synthesized and secreted by gonadotrophs present in the anterior pituitary gland. FSH is a heterodimeric glycoprotein consisting of an alpha chain of 92 amino acids and a beta chain of 118 amino acids. FSH regulates the development, growth, pubertal maturation, and reproductive processes of the body. Increase in FSH secretion causes ovulation. In sexually-mature males, FSH (assisted by testosterone) acts on spermatogonia stimulating the production of sperm. In sexually-mature females, FSH (assisted by LH) acts on the follicle to stimulate it to release estrogens. In female who has recently undergone menopause has a high level of FSH concentration in the serum.

(c) Luteinizing hormone (LH): Luteinizing hormone is a hormone produced by gonadotroph cells in the anterior pituitary gland. It is also a heterodimeric glycoprotein consisting of 92-amino acid alpha chain and a beta chain of 121 amino acids. In females, an acute rise of luteinizing hormone triggers ovulation and development of the corpus luteum. LH levels are normally low during childhood and high after menopause. In males, LH stimulates the Leydig cell to produce testosterone. Low secretion of LH can result in hypogonadism. These conditions lead to hypothalamic suppression, Kallmann syndrome, Hyperprolactinemia etc.

(d) Prolactin: Prolactin is also known as luteotropic hormone. It is a protein which is made up of 198 amino acids. During pregnancy it helps in the preparation of the breasts for future milk production. Increased serum concentrations of prolactin during pregnancy cause enlargement of the mammary glands of the breasts and prepare for the production of milk. After birth, prolactin promotes the synthesis of milk. Prolactin promotes neurogenesis in maternal and foetal brains. Prolactin has important cell cycle related functions as a growth factor, differentiating factor and anti-apoptotic factor.

(e) Growth Hormone (GH): Growth Hormone is also known as somatotropin. GH is a protein made up of 191 amino acids. The growth hormone-secreting cells are stimulated to produce and release ggrowth hormone by the intermittent arrival of growth hormone releasing hormone from the hypothalamus. Growth hormone stimulates growth, cell reproduction and regeneration in vertebrates. Hyposecretion of growth hormone produces a short body. It can also cause delayed sexual maturity. In adults, deficiency causes pituitary adenoma or other structural lesions or trauma and rarely idiopathic GHD. Hypersecretion of growth hormone leads to gigantism in childhood. In adults, it leads to acromegaly.

(f) Adrenocorticotropic hormone (ACTH): ACTH is also known as corticotrophin. ACTH is a peptide of 39 amino acids. It is an important component of the hypothalamic-pituitary-adrenal axis. ACTH acts on the cells of the adrenal cortex and stimulates them to produce glucocorticoids, mineralocorticoids, androgens and in foetus, dehydroepiandrosterone sulphate. Rapid actions of ACTH include stimulation of delivery of cholesterol to mitochondria where P450scc enzyme (Cholesterol side-chain cleavage enzyme) is located. Hyposecretion of ACTH in the pituitary leads to hypocorticism, Addison's disease. Hypersecretion of ACTH causes Cushing's disease.

2. Posterior Lobe: The posterior pituitary comprises the posterior lobe of the pituitary gland. It consists mainly of axons extending from the supraoptic and paraventricular nuclei of the hypothalamus. Posterior lobe of the pituitary releases two hormones into the circulation, both synthesized in the hypothalamus.

(a) Vasopressin: Vasopressin is also known as arginine vasopressin, argipressin or antidiuretic hormone. Vasopressin is a peptide made up of 9 amino acids. Vasopressin acts on the collecting ducts of the kidney to facilitate the reabsorption of water into the blood and reduce the volume of urine formed. Deficiency of vasopressin leads to diabetes insipidus, a condition where there is excessive loss of urine and hypernatremia. High levels of vasopressin secretion may lead to hyponatremia.

(b) Oxytocin: Oxytocin is a mammalian hormone that acts mainly as a neuromodulator in the brain. Oxytocin is a peptide of 9 amino acids. Oxytocin is best known for its roles in sexual reproduction, in particular during and after childbirth. It acts on certain smooth muscles stimulating contractions of the uterus at the time of birth and release of milk when the baby begins to suckle.

3. Intermediate lobe: The intermediate lobe is the boundary between the anterior and posterior lobes of the pituitary. It consists of three types of cells - basophils, chromophobes, and colloid-filled cysts.

The intermediate lobe of the pituitary secretes the melanocyte-stimulating hormone. The melanocyte-stimulating hormone stimulates the production and release of melanin by melanocytes present in the skin and hair.

Pheromones:

Pheromones are chemicals that are secreted in our sweat and other bodily fluids which release neurotransmitters that directly modify the behaviour of the opposite sex, such as triggering sexual excitement. The word ‘pheromone’ comes from the Greek word ‘phero’ which means "to bear" and ‘hormone’ which means "impetus". There are alarm pheromones, food trail pheromones, sex pheromones, and many other pheromones affect behaviour or physiology. The first pheromone that was identified in 1956 was a powerful sex attractant for silkworm moths. The least amount of it made male moths beat their wings madly in a flutter dance. The term "pheromone" was introduced by Peter Karlson and Martin Luscher in 1959. Strong pheromones can be a warning signal to predators to stay away or it can be also a signal that the prey animal is indigestible. Certain plants emit alarm pheromones when grazed upon by herbivorous animals resulting in tannin production in neighbouring plants. These tannins make the plants less appetizing.

Growth factors: Growth factors are signaling molecules which bind specifically to the receptor molecule embedded in either the cytoplasm or plasma membrane or nucleus of a cell. The vast majority of receptors are activated by binding to secreted growth factors. Many growth factors, regulating development in multicellular organisms act at short range as in paracrine signaling or act where the cells can respond to substances that they themselves release as in case of autocrine signaling. For example, the insulin receptor binds insulin and related hormones called insulin-like growth factors 1 and 2.

Individual growth factor proteins tend to occur as members of larger families of structurally and evolutionarily related proteins. Few families of growth factors are listed below:

(a) **Epidermal growth factor (EGF):** Epidermal growth factor is a growth factor that stimulates cell growth, proliferation and differentiation by binding to its receptor EGFR. Human EGF is a 6045-Da protein with 53 amino acid residues and three intramolecular disulfide bonds.

(b) **Fibroblast growth factor (FGF):** Fibroblast growth factors are a family of growth factors involved in angiogenesis, wound healing and embryonic development. The FGFs are heparin-binding proteins and interactions with cell-surface-associated heparan sulphate proteoglycans are essential for FGF signal transduction. FGFs play an important role in the processes of proliferation and differentiation of wide variety of cells and tissues.

(c) Insulin-like growth factor (IGF): The insulin-like growth factors (IGFs) are proteins with high sequence similarity to insulin. IGFs are part of a complex system that cells use to communicate with their physiological environment. This complex system consists of two cell-surface receptors (IGF1R and IGF2R), two ligands (IGF-1 and IGF-2), a family of six high-affinity IGF-binding proteins (IGFBP-1 to IGFBP-6), as well as associated IGFBP degrading enzymes, referred to collectively as proteases.

Role of growth factors in medicine:

Growth factors have been increasingly used in the treatment of hematologic and oncologic diseases and cardiovascular diseases like leukemias, angiogenesis for cardiovascular diseases, aplastic anaemia neutropenia, myelodysplastic syndrome (MDS) and bone marrow transplantation.

Keywords: Hormone, autocrine, paracrine, endocrine, pheromones, growth factors

Interesting facts:

- The first hormone to be discovered is “Secretin”.
- William Bayliss (1860-1924) and Ernest Starling (1866-1927) discovered secretin in 1902.
- Glutamate is a positive autocrine signal for glucagon release.

Questions:

1. Based on the biochemical nature, how are hormones classified?
2. Describe the various types of endocrine glands.
3. What are pheromones?
4. What are growth factors?
5. Classify cell signaling in animals with example.

References:

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. (2002). Molecular Biology of the Cell, 4^{th} ed. Taylor & Francis, Inc.

Cooper, G. M., Hausman, R. E. (2007). The Cell: A Molecular Approach, 4^{th} ed. Sinauer Associates, Inc.

Lodish, H., Berk, A., Matsudaira, P., Kaiser, C. A., Kreiger, M., Scott, M. P., Zipursky, L., Darnell, J. (2003). Molecular Cell Biology, 5^{th} ed. Freeman, W. H. & Company.

Berg, J. M., Tymoczko, J. L., Stryer, L. (2002). Biochemistry, 5^{th} ed. Freeman, W. H. & Company.

Module 4 Lecture 2

Plant growth factors

Plants need certain optimum conditions for its growth and development which are summed up as plant growth factors. These are specific requirements of plant cells. The plant growth factors can be studied under:

- Nutritional plant growth factors
- Environmental plant growth factors

Nutritional plant growth factors: Plants require adequate amount of nutrition for their better growth. The basic nutrients required for plant growth are:

(1) Macronutrients

(2) Micronutrients

(3) Water

Macronutrients: The nutrients which are required by the plants in large quantities are termed as macronutrients. There are six elements in the soil which fall into this category. These are nitrogen, potassium, magnesium, calcium, phosphorus and sulfur.

a) Nitrogen: Nitrogen is essential for growth as it is an important part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy. It is an essential part of chlorophyll involved in photosynthesis. Nitrogen improves the quality of the leaf and the foliage crops and also increases seed and fruit production; thus helping in rapid plant growth.

b) Potassium: Potassium activates enzymes necessary for starch synthesis, photosynthesis, energy metabolism, nitrate reduction and sugar degradation in plants. Potassium plays a vital role in reducing water loss from leaves and increases the ability of the roots to take up water from the soil. Potassium improves winter hardiness, drought tolerance, reduction to diseases.

c) Magnesium: Magnesium is essential for photosynthesis as it is an essential part of chlorophyll in all green plants. It also activates many plant enzymes essential for growth.

d) Calcium: Calcium is an essential part of the structure of cell wall in plants, providing normal transport and retention of other elements and strength in the plants. It also counteracts the effect of organic acids and alkali salts within plants.

e) Phosphorus: Phosphorus is essential for photosynthesis, plant maturation, withstanding stress, rapid growth of roots and encourages blooming. It is also involved in the formation of starches, sugars, oils etc.

f) Sulfur: Sulfur improves growth of roots, seed production and makes the plant resistant to cold. It is essential for protein production in plants. Sulfur also promotes activity and development of vitamins and enzymes and helps in chlorophyll formation.

Micronutrients:

The nutrients that are required by the plants in smaller quantities are termed as micronutrients. There are eight elements which are termed as micronutrients. These eight micronutrients include iron, zinc, molybdenum, manganese, boron, copper, cobalt and chlorine.

Iron: Iron is essential for the production of chlorophyll. Iron is a fundamental component of many enzymes associated with nitrogen reduction and fixation, energy transfer and lignin formation. Iron is associated with sulfur in plants to form compounds that catalyze other reactions. Lipoxygenases is a very common example of iron containg enzyme involved in deoxygenation of polyunsaturated fatty acids in plant.

Zinc: Zinc is an important component of various enzyme systems for protein synthesis, energy production and growth regulation. Zinc is essential for the transformation of carbohydrates and regulates the consumption of sugars. Zinc is essential for proper mobility of solutes and essential nutrients in plants. Few common examples of Zn containing enzymes are alcohol dehydrogenase, Cu-*Zn* superoxide dismutase, carbonic anhydrase, and RNA polymerase.

Molybdenum: Molybdenum is an essential component of the enzymes relating to nitrogen fixation by bacteria. Molybdenum is involved in protein synthesis, nitrogen metabolism and sulfur metabolism. Molybdenum plays a significant role in pollen formation.

Manganese: Manganese has a significant role to play in nitrogen metabolism, photosynthesis and other plant metabolisms. Manganese functions with the enzyme systems involved in carbohydrates breakdown.

Boron: Boron is essential for cell wall formation, production of sugar and carbohydrates. Boron helps in seed, fruit and grain development.

Copper: Copper is essential for reproductive growth. Copper is essential for the utilization of proteins and helps in root metabolism. It is essential for the metabolism of carbohydrate and nitrogen metabolism and is required for lignin synthesis needed for the strength of cell wall.

Cobalt: Cobalt is essential for nitrogen fixation and plays a vital role in protein synthesis.

Chlorine: Chlorine plays an important role in plant metabolism. It is essential for stomatal opening and electrical charge balance in physiological functions in plants. Further, it restricts wilting.

Water: Water is one of the most essential factors required for the growth of plants. A majority of growing plants contain as much as 90% water. Water plays a crucial role for efficient photosynthesis, respiration, transpiration and transportation of minerals and other nutrients through the plant. Water is responsible for functioning of opening of stomata in leaves and is also the source of pressure for the directed growth of roots through the soil. The role of water in plant growth is emphatically summarized in Table 1.

Table 1. Role of water in plant growth vs reduced water supply to plants

Role of water in plants	Effect of reduced water supply to plants
Primary component of photosynthesis and transpiration	Reduced plant growth and vigour
Turgor pressure	Wilting
Solvent to move minerals from the soil upto the plant NO_3^-, NH_4^+, $H_2PO_4^-$, HPO_4^{2-}, K^+, Ca^{2+}, Mg^{2+}, HSO_4^{2-}, $H_2BO_3^-$, Cl^-, Co^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Mn^{2+}, Zn^{2+}, MoO_4^{2-}	Reduced plant growth and vigour Nutrient deficiencies
Solvent to move products of photosynthesis throughout the plant, including down to the root system	Reduced health of roots which leads to reduced health of plant
Regulation of stomatal opening and closure, thus regulating transpiration and photosynthesis	Reduced plant growth and vigour Reduced cooling effect leading to warmer micro climate temperatures
Source of pressure to move roots through soil	Reduced root growth leading to reduced plant growth and vigour
Medium for biochemical reactions	Reduced plant growth and vigour

Environmental plant growth factors:

There are various environmental factors which has a significant role to play in enhancing the growth of plants. The environmental plant growth factors include:

(1) Light
(2) Temperature
(3) Relative humidity
(4) Carbon dioxide and Oxygen
(5) Soil

(1) Light: Light quality refers to the color or wavelength reaching the plant's surface. Adequate light is one of the most important factors that influence the growth of plants and it is the quality, quantity and duration of light exposure which matters. Various natural and artificial light sources can be used to provide light to the plants. Red and blue light have the greatest impact on plant growth whereas green light is least effective. Blue light is essential for the vegetative growth of the leaves of plants whereas combination of red and blue light promotes flowering in plants. There are certain plants which require less light for their growth. In such cases, light can be filtered using protective shelters so that the plants are exposed to minimum required amount of sunlight. The more sunlight a plant receives, the higher will be its photosynthetic rate. However, leaves of plants growing in low light readily excoriate when moved to a bright location having intense sunlight. Over time, as the wax content on a leaf increases and the plant grows it becomes more sun tolerant. When starting indoor transplants, generally plants are given 12-14 hours of light per day. Plants are generally intolerant to continuous light for 24 hours.

Light quality is a major consideration for indoor growing of the plants.

- Fluorescent cool white lamps are high in the blue range and are used for starting seeds germination.
- For flowering plants that need more red light, broad spectrum fluorescent bulbs are used.
- Incandescent lights are high in red and red-orange, but generally it produces too much heat for use in supplementing plant growth. Figure 1 shows the graph of relative efficiency of various colors of light in photosynthesis.

Figure 1. Relative efficiency of various colours of light in photosynthesis.
(X axis: Various colours of light; Y axis: Relative efficiency of flowering plant)

Photoperiod: The flowering response of many plants is controlled by the photoperiod which is the length of uninterrupted darkness. The plant's reproductive cycle is timed to the amount of light available. Photoperiod response can be divided into three types.

(a) Short day plants (SDP): SDPs flower in response to long periods of night darkness as shown in Figure 2. *Short-day plants flower when day lengths are less than the critical photoperiod.* Some short-day obligate plants are: Chrysanthemum, Poinsettia, Strawberry, Coffee, Tobacco, Common duckweed (*Lemna minor*), Cocklebur (*Xanthium*), Maize (tropical cultivars only). Some examples of short-day facultative plants are: Sugar cane, Rice, Cotton (*Gossypium*), Hemp (*Cannabis*).

(b) Long day plants (LDP): LDPs flower in response to short periods of night darkness as shown in Figure 2. *Long-day plants flower when day lengths exceed the critical photoperiod.* Examples include onions and spinach. Some examples of long-day obligate plants are: Carnation (*Dianthus*), Oat (*Avena*), Clover (*Trifolium*), Henbane (*Hyoscyamus*), Ryegrass (*Lolium*), Bellflower (*Campanula carpatica*). Some long-day facultative plants are: Pea (*Pisum sativum*), Lettuce (*Lactuca sativa*), Wheat (*Triticum aestivum*, spring wheat cultivars), Barley (*Hordeum vulgare*), Turnip (*Brassica rapa*), *Arabidopsis thaliana*.

(c) Day neutral plants (DNP): DNP flower without regard to the length of the night but typically flower earlier and more profusely under long daylight regimes. Day neutral strawberries provide summer long harvesting (except during heat extremes).

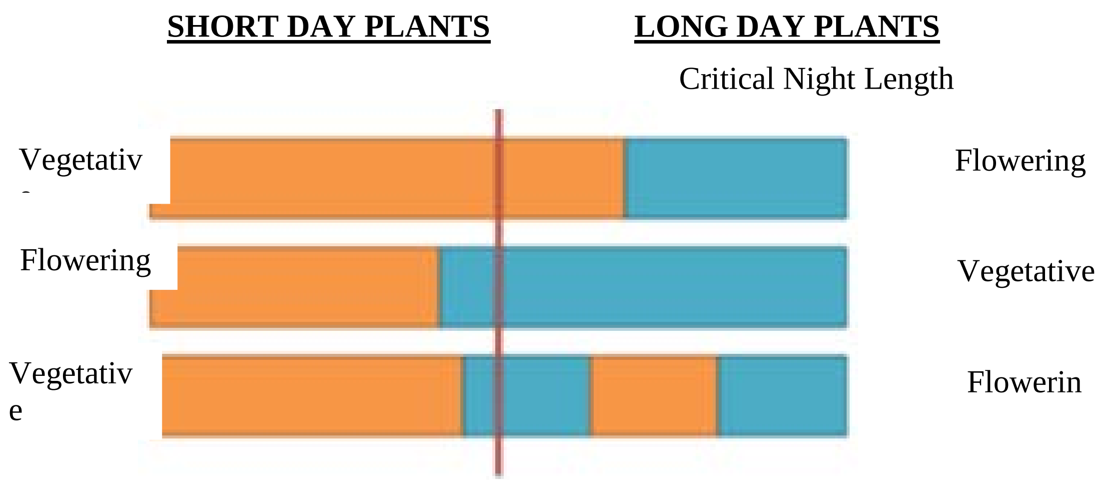


Figure 2: Photoperiod and Flowering
Short day plants flower with uninterrupted long nights.
Long day plants flower with short nights or interrupted long nights
(Left side: Short day plants flower with uninterrupted long nights.
Right side: Long-day plants flower with short nights or interrupted long nights.)

(2) Temperature: Temperature is a crucial factor that has an influence on the growth of plants. Temperature of the surrounding atmosphere and the temperature of the soil play an important role. For many of the plant processes like photosynthesis, respiration, germination and flowering, optimum temperature is one of the pre-requisites. Usually cold-season plants have 12.7 – 18.3 °C as the optimum temperature for germination whereas warm-season plants germinate at 18.3 – 23.8 °C. The **Temperature Comparison between Cool Season and Warm Season Vegetables is as shown in Table 2.** The temperature range for optimum photosynthesis and respiration vary with individual requirements of the plants and also among the species of plants.

Table 2 Temperature Comparison between Cool Season and Warm Season Vegetables

	Cool Season: broccoli, cabbage, and cauliflower	**Warm Season:** tomato, pepper, squash and melons
Germination	4.4 °C – 32.2 °C 26.6 °C optimum	10°C -37.7 °C 26.6 °C optimum
Growth	**Daytime** 18.3 °C – 26.6 °C preferred 4.4 °C minimum **Night time** greater than 0 °C for tender transplants down to mid -6.7 °C for established plants	**Daytime** 30 °C optimum 15.5 °C minimum Below 12.8 °C will stunt plant, reducing yields. **Night time** above 0 °C
Flowering	Temperature extremes lead to bolting and buttoning.	**Daytime**: Greater than 35 °C by 10 a.m., blossoms abort. **Night time**: Below 12.8 °C, non- viable pollen (use blossom set hormones).
Soil	**Winter** Use organic mulch to cool soil. Since seeds germinate best in warm soils, use transplants for spring planting, and direct seeding for mid-summer plantings (fall harvest).	**Summer** Use black plastic mulch to warm soil, increasing yields and earliness of crop

(3) Relative humidity: Moisture is defined as the ratio of water vapour in the air to the amount of water in the air. It is a very important factor in growth of plants. The relative humidity in the air is used by the plants and is very crucial for the transpiration of the plants. Transpiration is highest during hot, dry and windy days while transpiration slows down during cool and humid days. Water moves from areas of high relative humidity to areas of lower relative humidity. Inside a leaf, the relative humidity between cells approaches 100%. When the stomata opens, water vapors inside the leaf rush out forming a bubble of higher humidity around the stomata on the outside of the leaf and carbon dioxide move into the leaf through the stomata as shown in Figure 3. The difference in relative humidity around the stomata and adjacent air regulates transpiration rates and pulls water up through the xylem tissues. When the supply of water from the roots is inadequate, the stomata closes, photosynthesis shuts down, and plants can wilt.

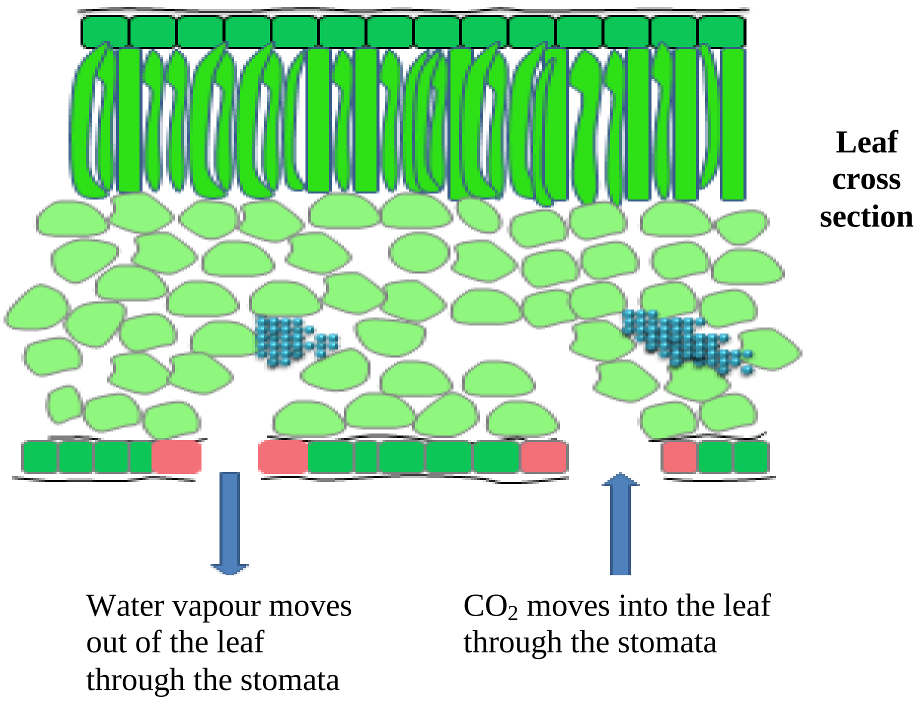


Figure 3: Water vapor moves out and carbon dioxide move into the leaf through the stomata

(4) Carbon dioxide and oxygen: Carbon dioxide is one of the vital elements for plant growth. The manufacturing of sugar by plants requires the presence of carbon dioxide. Plant growth requires a tremendous amount of carbon dioxide. Plants can use as much as 1500 ppm of carbon dioxide. When all other growth influencing factors are kept in their ideal ranges, CO_2 becomes the limiting factor. This means as carbon dioxide is increased, growth rates and yields also increases. Oxygen is essential for plant respiration and utilization of photosynthesis byproducts. No nutrient absorption occurs at the root zone unless oxygen is present. At a molecular level, oxygen is required to transmit nutrients across the cell wall and into the roots. As oxygen levels are increased at the root zone, nutrient absorption continues to increase as well. Plants produce oxygen gas during photosynthesis to produce glucose but then require oxygen to undergo aerobic cellular respiration and break down this glucose to produce ATP. When oxygen is absent, hypoxia occurs which affect nutrient uptake of a plant and inhibits respiration within the root cells.

(5) Soil: Soil is the outermost layer of the surface of the earth in which plants grow. Soil with proper humidity and the right balance of all the minerals and nutrients is one of the essential factors instrumental in plant growth. The type of soil and the quality and the nutrients required in it vary according to the plant species. The right pH balance, which measures the alkalinity or acidity of the soil and presence of certain chemicals, is also instrumental in the growth of plants. pH influences availability of certain nutrients. For most plant life, the most favorable pH value is between 6 - 6.8. The soil serves the needs of the plant by providing: water, air, nutrients and stability. The ability of a soil to provide these services may be evaluated by key soil attributes as shown in Table 3)

Table 3: Soil attributes relevant to plants

Key soil attribute	Relevance to plants
Wetness	Water supply, exclusion of air and, consequently, exclusion of oxygen
Root barrier	Controls the depth of soil available for roots to extract water and nutrients, and to anchor the plant
Stoniness	Stones and rocks dilute the volume of soil within the root depth that is available for water storage and nutrients
Porosity	Promotes stability by allowing deep rooting. Drains excess water, and circulates air to roots
Natural nutrient status	Controls nutrient supply and reserves
Drought proneness	An interaction between climate and soil attribute

Interesting Facts:

- Photoperiodism is responsible for the geographical distribution of many plants worldwide.
- Bulbing in onions is primarily controlled by photoperiod - day length - as the days become longer, plants begin to bulb.

Questions:

1. What are plant growth factors? How can it be classified?
2. What are macronutrients? Name them.
3. What are micronutrients? Name them.
4. What are environmental plant growth factors? Give example.
5. What are short day plants? Give two examples of short day plants.
6. What are long day plants? Give two examples of long day plants.
7. What are day neutral plants? Give two examples of day neutral plants.
8. ________ flower in response to short periods of night darkness.
    (a) Short day plants
    (b) Long day plants
    (c) Day neutral plants
9. What are nutritional plant growth factors? Classify each of them in details.
10. What are macronutrients? Describe the function of each of the macronutrients.
11. What are micronutrients? Describe the function of each of the micronutrients.
12. Describe the role of water in plant growth.
13. What are environmental plant growth factors? Describe each factor in details.
14. Describe how the effect of light can contribute to the growth of plants.

References:

- *Taiz, L.* and *Zeiger, E. (2002). Plant Physiology.* Sinauer Associates.
- Bouma, D. (1983) Diagnosis of mineral deficiencies using plant tests. In *Inorganic Plant Nutrition* (Encyclopedia of Plant Physiology, New Series, Vol. 15B), A. Läuchli and R. L. Bieleski, eds., Springer, Berlin, pp. 120–146.
- Brady, N. C. (1974) The Nature and Properties of Soils, 8th ed. Macmillan, New York.

Module 4 Lecture 3
Plant hormones

We have studied animal hormones in previous lectures. Plants also have analogous signaling molecules, called phytohormones. These are a group of naturally occurring, organic substances which influence the physiological processes at low concentrations. Plant hormones are physiological intercellular messengers which are needed to control the complete plant lifecycle, including growth, germination, rooting, fruit ripening, flowering, foliage and death. They are secreted in response to environmental factors such as light, temperature, abundance of nutrients, drought conditions, chemical or physical stress. Levels of hormones change over the lifespan of a plant and they are also dependent upon environment and seasons.

Every aspect of plant growth and development is under hormonal control to some degree. A single hormone can regulate a diverse array of cellular and developmental processes, while at the same time multiple hormones often influence a single process. Right combination of hormones is vital to achieve the desired behavioral characteristics of cells and the productive development of plants as a whole. The application of growth factors allows synchronization of plant development to occur. For example, ripening bananas can be regulated by using desired atmospheric ethylene levels. Other applications include rooting of seedlings or the suppression of rooting with the simultaneous promotion of cell division as required by plant biotechnologists.

Five major classes of plant hormones are known in plants. With progressing research, more active molecules are being found and new families of regulators are emerging, one example being polyamines such as putrescine or spermidine.

(1) Auxin
(2) Gibberellin
(3) Cytokinin
(4) Abscisic acid
(5) Ethylene

(1) Auxin:

The term auxin is derived from the Greek word 'auxein' which means to grow. They are a class of plant hormones which has a cardinal role in coordination of many growth and behavioral processes in the plant's life cycle essential for development of plant. Auxin is the first plant hormone to be identified. They have the ability to induce cell elongation in stems and resemble indoleacetic acid (the first auxin to be isolated) in physiological activity.

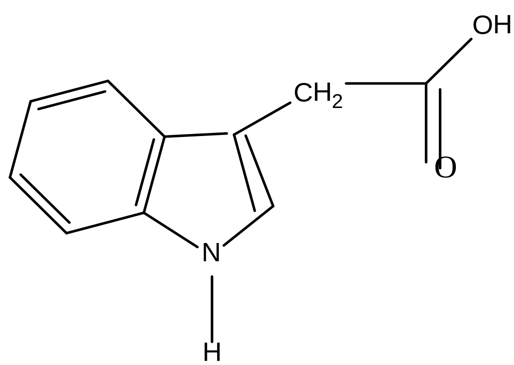


Figure 1: Auxin

Indole-3-acetic acid (IAA) is the main auxin in most plants. IAA is transported is cell to cell.

Discovery of auxin: Darwin (1881) was the first person who discovered the existence of auxin in plants, the first phytohormone known. He noted that the first leaf (coleoptile) of canary grass (*Phalaris canariensis*) was very sensitive and responsive to light and he demonstrated the bending of the grass coleoptiles towards unilateral source of light. This bending occurred only when the coleoptile was also illuminated. When the tip of the coleoptiles was covered with a black cap, it resulted in loss of sensitivity of the plant towards the light as shown in Figure 2. Darwin concluded that some influence that causes curvature is transmitted from the coleoptile tip to the rest of the shoot. Boysen – Jensen (1913) also made similar observations on oat (*Avena*) coleoptiles as shown in Figure 2. Paal (1918) demonstrated that when the decapitated coleoptiles tip was replaced on the cut end eccentrically, more growth resulted on the side which causes bending even when this is done in complete darkness.

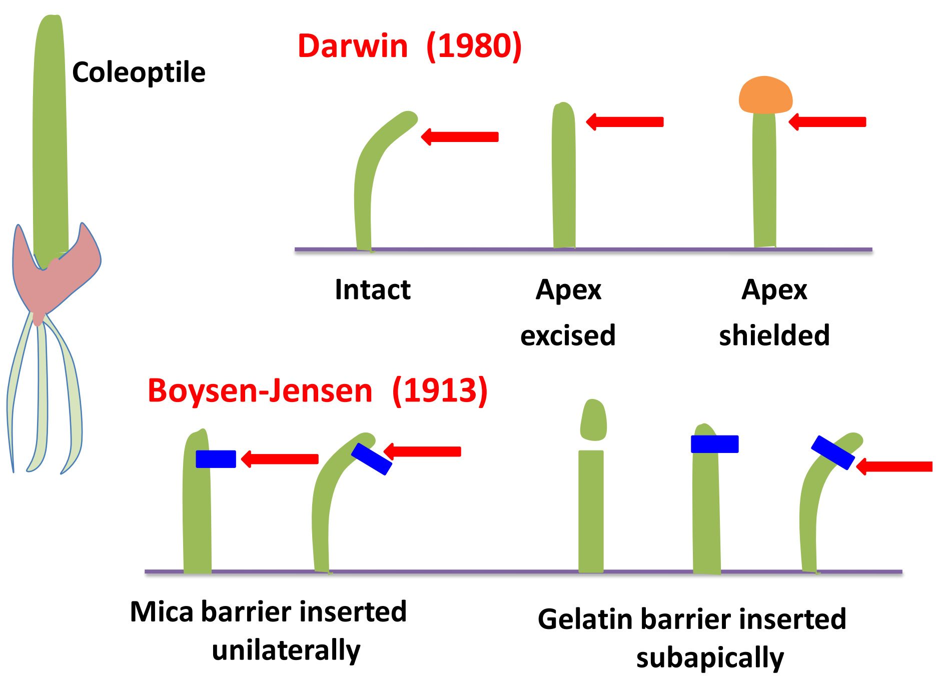


Figure 2: Discovery of auxin: phototropic response of grass seedlings

Sites of biosynthesis of auxin: IAA is synthesized primarily in actively growing tissue in leaf primordia and young leaves, fruits, shoot apex and in developing seeds. It is made in the cytosol of cells.

Tryptophan-dependent Pathways for auxin synthesis: Tryptophan, one of the protein amino acids, is the precursor of auxin biosynthesis. The conversion of tryptophan to Indole Acetic Acid can occur by either transamination followed by a decarboxylation or decarboxylation followed by a transamination. Formation of IAA via an oxime (C=NOH) and nitrile (CN) is shown in Figure 3.

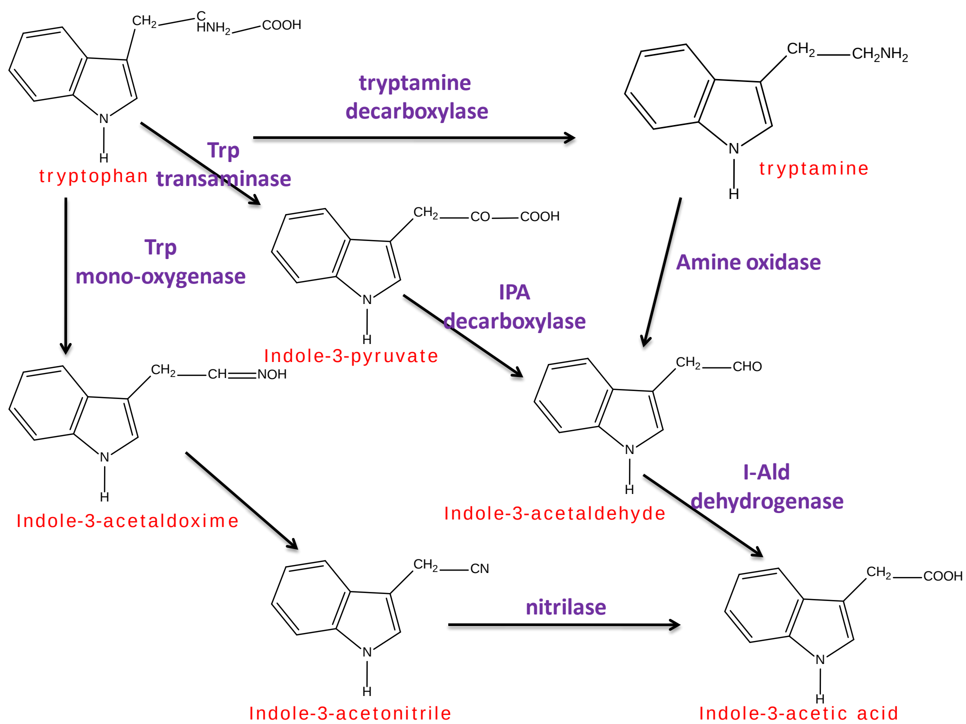


Figure 3: Biosynthesis of auxin from Tryptophan

Classification of auxins: Auxins are classified into two types based on its occurrence, if they occur naturally or are synthesized artificially.

1. Natural auxins

2. Synthetic auxins

Natural auxins: The four naturally occurring (endogenous) auxins are Indole-3-acetic acid, 4-chloroindole-3-acetic acid, phenylacetic acid and indole-3-butyric acid; only these four are synthesized by plants.

Synthetic auxins: Synthetic auxin analogs include 1-naphthaleneacetic acid, 2,4-dichlorophenoxyacetic acid (2,4-D) and many others. Some synthetic auxins, such as 2,4-D and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), are used also as herbicides. Broad-leaf plants (dicots), such as dandelions, are much more susceptible to auxins than narrow-leaf plants (monocots) such as grasses and cereal crops, so these synthetic auxins are useful as synthetic herbicides.

Auxin signaling: Auxin binds to a receptor with ubiquitin ligase activity. This stimulates ubiquitination and degradation of a specific transcriptional repressor further leading to transcription of auxin-induced genes as shown in Figure 4.

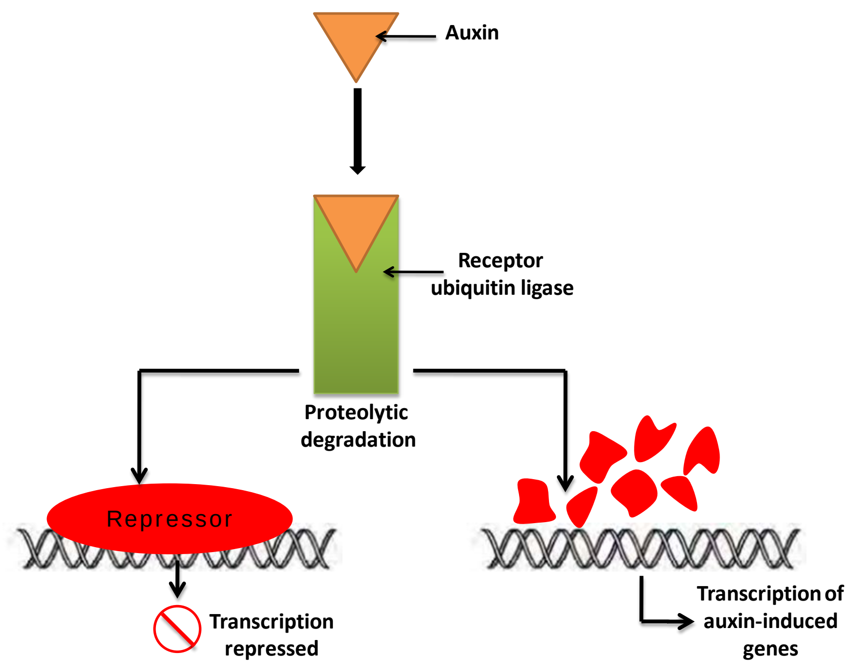


Figure 4: Auxin signaling

Functions of Auxin: Indole acetic acid regulates many responses: Cell elongation and wall relaxation and cell differentiation. It promotes differentiation of vascular tissue (i.e., xylem & phloem). IAA apparently stimulates the production of ethylene. IAA at more than 10^{-6} M concentration inhibits root elongation. However, very low concentration ($>10^{-8}$ M) favor root elongation. It stimulate root initiation both lateral roots and adventitious roots. Most plants do not initiate the production of flowers after auxin treatment except pineapple and its relatives belonging to Bromeliaceae. Once flowers are initiated, in many species, IAA promotes the formation of female flowers, especially in cucurbits (gourd family). Parthenocarpic fruit development is regulated by auxins. The apical meristem (apex) controls or dominates the development of the lateral buds. Apical dominance also occurs in roots. Auxin mediates the tropistic (bending) response of shoots and roots to gravity and light. It delays leaf senescence. Auxin may inhibit or promote (via ethylene) leaf and fruit abscission.

(2) Gibberlin:

Gibberellins (GAs) are a group of diterpenoid acids that function as plant growth regulators inflencing a range of developmental processes in higher plants including stem elongation, germination, dormancy, flowering, sex expression, enzyme induction and leaf and fruit senescence.

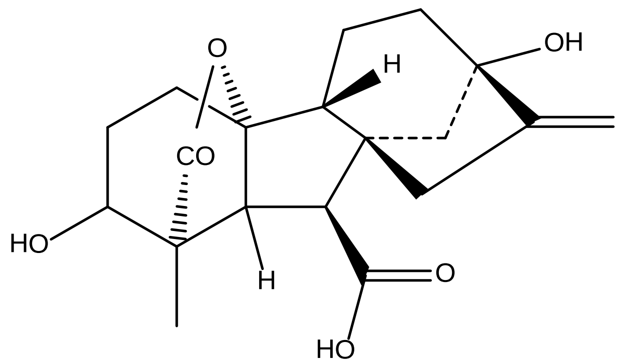


Figure 5: Gibberellin

Discovery of Gibberellin: Kurusawa, a Japanese plant pathologist, discovered gibberellin in 1926. When he was working in the rice fields, he observed that some of the rice seedlings grew much taller than the others which were found to be infected by a fungus, *Gibberella fujikuroi*. Yabuta and Yabuta and Sumiki (1938) demonstrated that some substances secreted by the fungus were probably responsible for more elongation (growth) of the seedlings. Till date, about 62 different gibberellins are known out of which 25 have been isolated from the fungus *Gibberella fujikuroi.*

Chemical structure of Gibberellins:

All gibberellins are derived from the ent-gibberellane skeleton. During the synthesis of gibberellins, the central 6-member ring is reduced to 5 carbons to make the basic gibberellin. The carbons are numbered 1 through 20. Gibberellins are diterpenes synthesized from acetyl CoA via the mevalonic acid pathway. They all have either 19 or 20 carbon units grouped into either four or five ring systems. The fifth ring is a lactone ring. They have been depicted in Figure 7.

Biosynthesis: In the formation of gibberellins 3 acetyl CoA molecules are oxidized by 2 NADPH molecules to produce 3 CoA molecules as a side product and mevalonic acid. Further Mevalonic acid is then phosphorylated by ATP and decarboxylated to form isopentyl pyrophosphate. 4 of these molecules form geranylgeranyl pyrophosphate which serves as the donor for all GA carbon atoms. This compound is then converted to copalylpyrophosphate which has 2 ring systems. Copalylpyrophosphate is then converted to kaurene which has 4 ring systems.

Subsequent oxidations reveal kaurenol (alcohol form), kaurenal (aldehyde form), and kaurenoic acid respectively. Kaurenoic acid is converted to the aldehyde form of GA_{12} by decarboxylation. GA_{12} is the 1st true gibberellane ring system with 20 carbons. From the aldehyde form of GA_{12} arise both 20 and 19 carbon gibberellins but there are many mechanisms by which these other compounds arise. Transport of Gibberellin in plants is non-polar. It moves from one part to another in the phloem. Due to the lateral movements between the two vascular bundles, gibberellins are translocated in the xylem.

Functions of Gibberellin: Gibberellins are involved in stem elongation. Many seedlings (eg. radish, lettuce, tomatoes etc.) when grown in petri dishes containing GA_3 solution, show elongation of hypocotyl. GA1 also causes hyperelongation of stems by stimulating both cell division and cell elongation. GAs cause stem elongation in response to long days GAs can cause seed germination in some seeds that normally require cold (stratification) or light to induce germination as shown in Figure 7. Barley is one such example. Gibberellins are known to stimulate the de-novo synthesis of numerous hydrolases, notably α-amylase in the aleurone cells that surround the starchy endosperm in barley. In seed germination in lettuce, the main signal stimulating gene expression of amylase and other germination-initiating enzymes is light. Thus the photoactivation is achieved by phytochrome in its Pfr form. GA stimulates the production of numerous enzymes, notably a-amylase, in germinating cereal grains.

3. Cytokinin:

Cytokinins are a class of phytohormones with a structure resembling adenine which promote cell division and have other similar functions to kinetin. This hormone is termed as "cytokinin" because they stimulate cell division (cytokinesis). Cytokinins promote cell division or cytokinesis, in plant roots and shoots. They are involved primarily in cell growth and differentiation, but also affect axillary bud growth, apical dominance and leaf senescence. Kinetin was the first cytokinin to be discovered and it is so named because of the compounds' ability to promote cytokinesis (cell division). Though it is a natural compound, it is not made in plants and therefore it is usually considered a "synthetic" cytokinin. The most common form of naturally occurring cytokinin in plants today is called zeatin which was isolated from corn (*Zea mays*). Cambium and other actively dividing tissues also synthesize cytokinins. Approximately 40 different structures of cytokinin are known. Other naturally occurring cytokinins include dihydrozeatin (DHZ) and isopentenyladenosine (IPA). Cytokinin concentrations are highest in meristematic regions and areas of continuous growth potential such as roots, young leaves, developing fruits, and seeds. Cytokinins have been found in almost all higher plants as well as mosses, fungi, bacteria and also in tRNA of many prokaryotic and eukaryotic organisms. Today there are more than 200 natural and synthetic cytokinins combined.

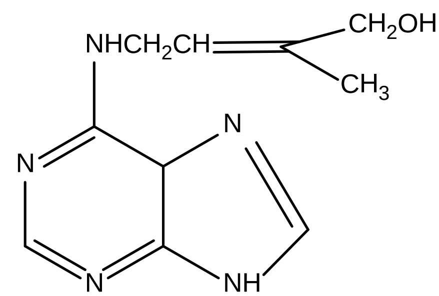


Figure 6: Cytokinin

Chemical nature of cytokinin:

Chemical nature of cytokinins is based on two types:

1. Adenine-type cytokinins
2. Phenylurea-type cytokinins

Adenine-type: These cytokinins are represented by kinetin, zeatin and 6-benzylaminopurine. Majority of the adenine-type cytokinins are synthesized in the roots. Cytokinin biosynthesis also takes place in the cambium and other actively dividing tissues.

Phenylurea-type: These cytokinins are represented by diphenylurea and thidiazuron (TDZ). Till now there is no evidence that the phenylurea cytokinins occur naturally in plant tissues.

Cytokinins are involved in both local and long distance signaling. Cytokinins are transported within the xylem.

Classes of cytokinin:

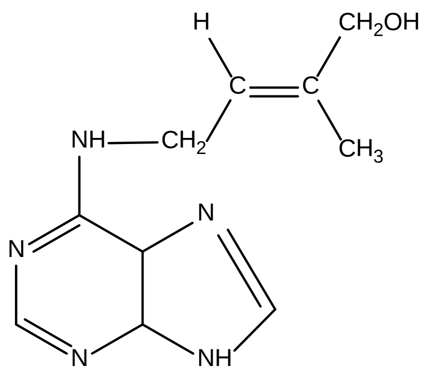
There are two classes of cytokinin hormone**:** They are as follows:

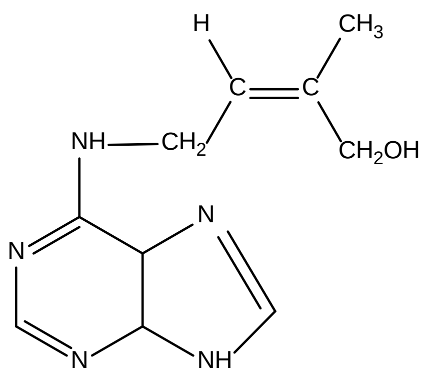
(i) Natural cytokinin

(ii) Synthetic cytokinins

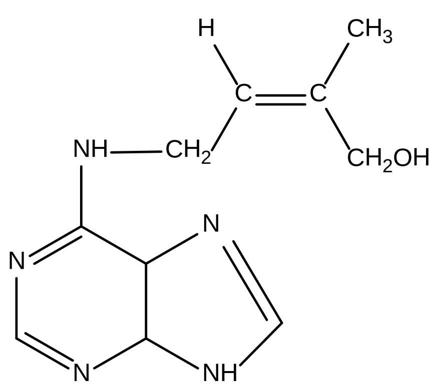
(i) Natural Cytokinin:

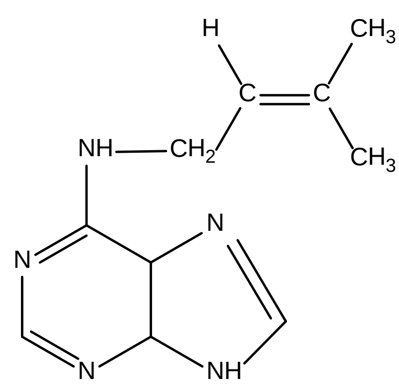
The most common form of naturally occurring cytokinin in plants today is called zeatin which was isolated from corn (*Zea mays*). Approximately 40 different structures of cytokinin are known. Other naturally occurring cytokinins include dihydrozeatin (DHZ) and isopentenyladenosine (IPA). Figure 7depicts some cytokinins.



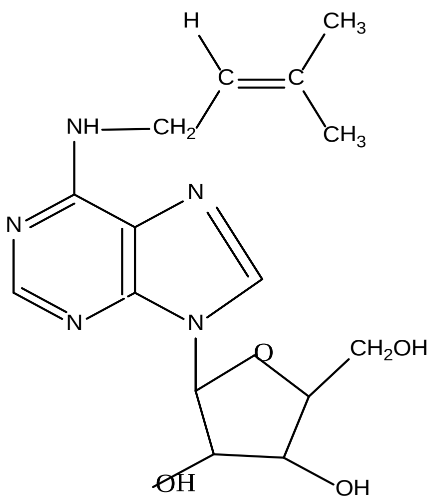


Trans-zeatin **Cis-zeatin**

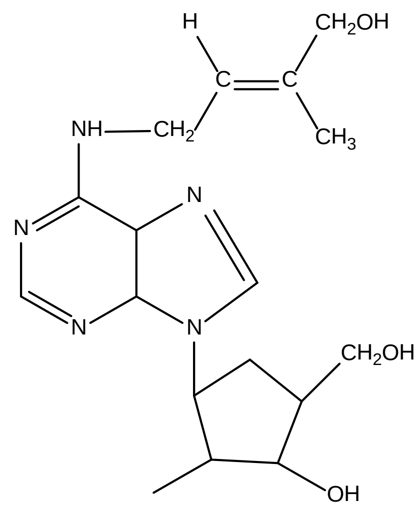




Dihydrozeatin **Isopentyladenine**



Isopentyladenine riboside



Trans-zeatin riboside

Figure 7: Cytokinins

(ii) Synthetic Cytokinin:

Kinetin is also known as synthetic cytokinin.

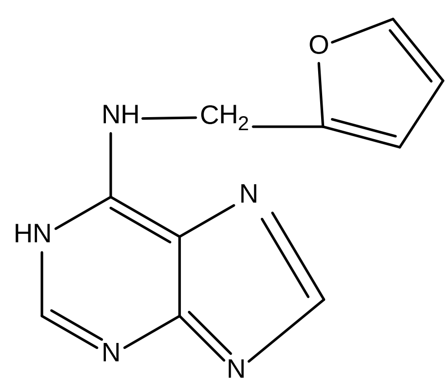


Figure 8: Kinetin

Function of Cytokinin:

Stimulates cell division: Especially by controlling the transition from G2 mitosis. This effect is moderated by cyclin-dependent protein kinases (CDK's) and cyclins. Stimulates morphogenesis (shoot initiation/bud formation) in tissue culture: In plant tissue cultures, cytokinin is required for the growth of a callus. Stimulates the growth of lateral buds- Cytokinin application to dormant buds causes them to develop. Witches' broom is caused by a pathogen *Corynebacterium fascians* (or *Agrobacterium tumefaciens*) that produces cytokinin which, in turn, stimulates lateral bud development. Thus apical dominance may be related to cytokinin too. Stimulates leaf expansion resulting from cell enlargement: Cytokinins stimulate the expansion of cotyledons. The mechanism is associated with increased plasticity of the cell wall. May enhance stomatal opening in some species. Promotes the conversion of etioplasts into chloroplasts via stimulation of chlorophyll synthesis.

4. Abscicic acid:

Abscisic acid (ABA) is the major phytohormone that controls plant's ability to survive in harsh, changing environment. ABA promotes abscission of leaves and fruits; hence it is this action that gave rise to the name of this hormone 'abscisic acid'. ABA is a naturally occurring compound in plants. The ABA signaling pathway is conserved across all plants, including mosses, and it is considered as an early adaptation to the terrestrial environment. ABA is found in leaves (where it is partially synthesized), stems, and green fruits. It is generally associated with negative-feedback interactions or stress-related environmental signals such as drought, freezing temperatures and environmental pollutants

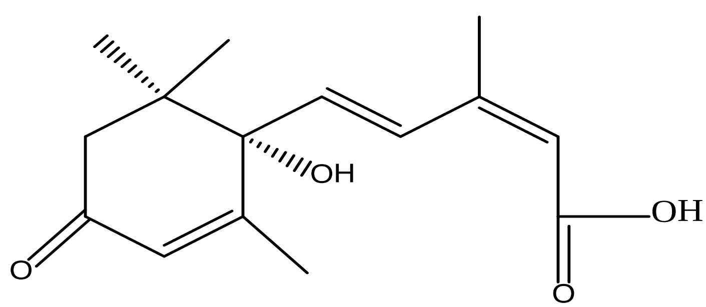


Figure 9: Abscisic acid

Chemical nature of abscisic acid:

Abscisic acid is a naturally occurring compound in plants. Abscisic acid (ABA) is an isoprenoid plant hormone, which is synthesized in the plastids by the 2-*C*-methyl-D-erythritol-4-phosphate (MEP) pathway; It is a sesquiterpenoid (15-carbon) which is produced partially via the mevalonic pathway in chloroplasts and other plastids. Since it is sythesized partially in the chloroplasts, biosynthesis of ABA primarily occurs in the leaves. The production of ABA is accentuated by stresses such as water loss and freezing temperatures.

Functions of Abscisic acid:

Some of the physiological responses of Abscisic acid are listed below:

(1) Antitranspirant: Stimulates the closure of stomata by decreasing transpiration to prevent water loss (water stress brings about an increase in ABA synthesis). In angiosperms and gymnosperms (but not in ferns and lycopsids), ABA triggers closing of stomata when soil water is insufficient to keep up with transpiration.

Mechanism: ABA binds to receptors at the surface of the plasma membrane of the guard cells.

The receptors activate several interconnecting pathways which converge to produce a rise in pH in the cytosol. Transfer of Ca^{2+} from the vacuole to the cytosol. These changes stimulate the loss of negatively-charged ions (anions), especially NO_3^- and Cl^-, from the cell and also the loss of K^+ from the cell. The loss of these solutes in the cytosol reduces the osmotic pressure of the cell and thus turgor. The stomata close. ABA also promotes abscission of leaves and fruits (in contrast to auxin, which inhibits abscission). It is, in fact, this action that gave rise to the name abscisic acid. The dropping of leaves in the autumn is a vital response to the onset of winter when ground water is frozen — and thus cannot support transpiration — and snow load would threaten to break any branches still in leaf. Inhibits shoot growth but will not have as much affect on roots or may even promote growth of roots, induces seeds to synthesize storage proteins. It inhibits the affect of gibberellins on stimulating de novo synthesis of alpha-amylase. It also has some effect on induction and maintanance of dormancy. ABA inhibits seed germination in antagonism with gibberellins and induces gene transcription especially for proteinase inhibitors in response to wounding which may explain an apparent role in pathogen defense. Inhibits fruit ripening and is responsible for seed dormancy by inhibiting cell growth. It downregulates enzymes needed for photosynthesis.

5. Ethylene:

Ethylene (IUPAC name: ethene), unlike the rest of the plant hormone compounds is a gaseous hormone. Of all the known plant growth substance, ethylene has the simplest structure. It contains a carbon-carbon double bond, ethylene is classified as an unsaturated hydrocarbon. It is produced in all higher plants and is usually associated with fruit ripening. Ethylene which is also known as the 'death hormone' or 'ripening hormone' plays a regulatory role in many processes of plant growth, development and eventually death. Fruits and vegetables contain receptors which serve as bonding sites to absorb free atmospheric ethylene molecules. The overall effect is to hasten ripening, aging and eventually spoilage.

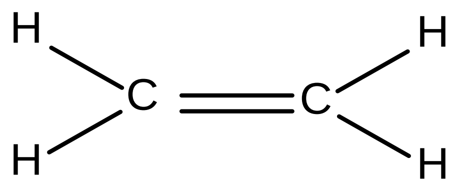


Figure 10: Ethylene

Functions of ethylene:

Ethylene has various physiological responses which are listed below:

Ethylene plays vital role in fruit ripening: The changes which typically takes place due to the stimulating effect of ethylene includes softening of the fruit due to the enzymatic breakdown of the cell walls, sugar accumulation, starch hydrolysis and disappearance of organic acids and phenolic compounds including tannins. Ethylene has the ability to initiate germination in certain seeds, such as cereals and break the dormancy. Ethylene increases the rate of seed germination of several species. Ethylene can also break bud dormancy and ethylene treatment is used to promote bud sprouting in tubers such as potatoes etc. It stimulates shoot and root growth along with differentiation. Ethylene induces abscission. Abscission takes place in specific layers of cells, called abscission layers, which become morphologically and biochemically differentiated during organ development. Weakening of the cell walls at the abscission layer depends on cell wall–degrading enzymes such as polygalacturonase and cellulase. Ethylene induces flowering in Bromeliaceae family plants which includes pineapple and its relatives. Flowering of other species of plants, such as mango, is also initiated by ethylene. Ethylene may change the sex of developing flowers on monoecious plants (plants which have separate male and female flowers).

The femaleness of diocious flowers in plants is stimulated by the production of ethylene. The promotion of female flower formation in cucumber is one example of this effect.Flower and leaf senescence stimulation is caused by ethylene. Exogenous applications of ethylene accelerate leaf and flower senescence. Enhanced ethylene production in plants is associated with the loss of chlorophyll and the fading of colours.

Role of plant hormones in tissue culture:

The culture of plant tissues or plant cells in a synthetic culture medium under controlled aseptic conditions is known as plant tissue culture. Plant tissue culture is the aseptic culture of plant protoplasts, cells, tissues or organs under conditions which lead to cell multiplication or regeneration of organs or whole plants. Tissue culture produces clones, in which all product cells have the same genotype. The culture medium provides all minerals and growth hormones necessary for the growth of cells. The controlled conditions give the culture a suitable microenvironment for the cell growth, proliferation and morphogenesis. During plant tissue culture, cells of small segments of plant tissue undergo repeated divisions to form masses of cells called calli. Plant tissue culture techniques are central to pioneering areas of applied plant science, including plant biotechnology and agriculture. Selected plants can be cloned and cultured as suspended cells from which plant products can be harvested. The management of genetically engineered cells to form transgenic whole plants requires tissue culture procedures; tissue culture methods are also required in the formation of somatic haploid embryos from which homozygous plants can be generated.

Plant tissue culture relies on the fact that many plant cells have the ability to regenerate a whole plant (totipotency). Single cells, plant cells without protoplasts, pieces of leaves, or roots can often be used to generate a new plant on culture media given the required nutrients and plant hormones. The composition of the medium, particularly the plant hormones and the nitrogen source has profound effects on the morphology of the tissues that grow from the initial explant. Thus, plant hormones are one of the most essential components of the medium used in plant tissue culture. For example, an excess of auxin will often result in a proliferation of roots, while an excess of cytokinin may yield shoots. A balance of both auxin and cytokinin will often produce an unorganized growth of cells or callus. Effect of different auxin and cytokinin concentration on tissue development is shown in Figure 11. The ratio of these two hormones can determine plant development:

↑ Auxin ↓Cytokinin = Root Development

↑ Cytokinin ↓Auxin = Shoot Development

Auxin = Cytokinin = Callus Development

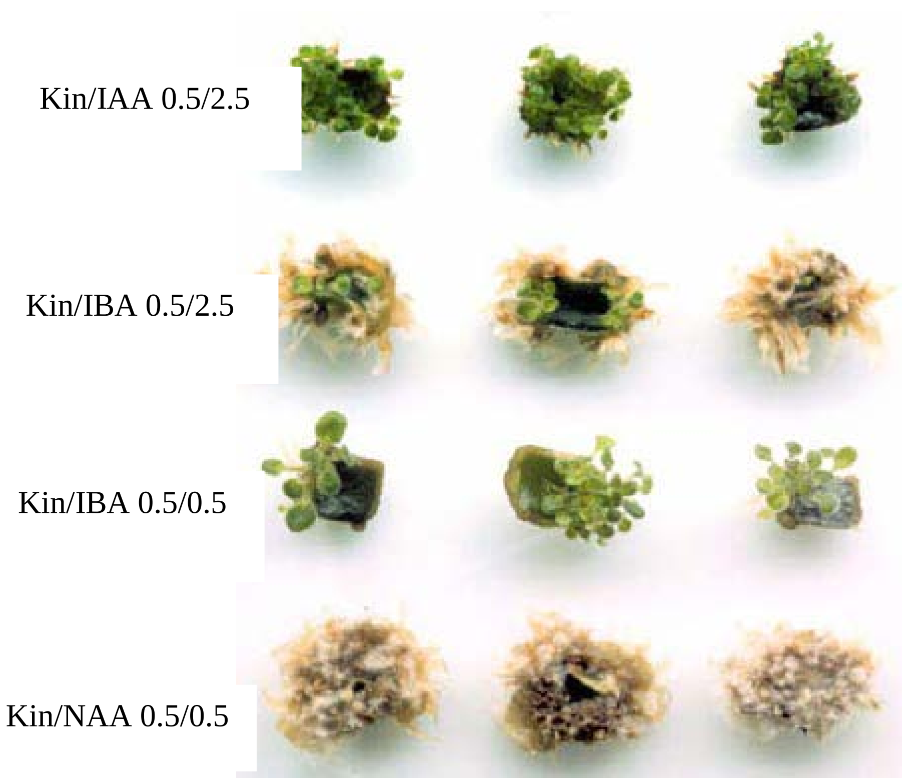


Figure 11: Effect of different auxin and cytokinin concentration on tissue development

(Kin– Kinetin; IAA– Indole acetic acid; IBA-Indole-3-butyric acid; NAA-Naphthaleneacetic acid)

Cytokinins are derived from adenine and produce two immediate effects on undifferentiated cells: the stimulation of DNA synthesis and increased cell division in tissue culture. Cytokinins also produce a delayed response in undifferentiated tissue which is the formation of shoot primordia. Although low tissue concentrations of cytokinins (e.g., 1×10^{-8} M zeatin) have clear effects during tissue culture, higher concentrations are found in actively dividing tissues such as those of plant embryos and developing fruits. Auxins are indole or indole-like compounds that stimulate cell expansion, particularly cell elongation in tissue culture. Auxins also promote adventitious root development. Only small amounts of auxin (1×10^{-6} M) are required to demonstrate an IAA response and even smaller amounts of synthetic auxin (e.g., NAA) are required for a tissue response during tissue culture. Synthetic auxins are more effective hormones that last for an extended length of time. Furthermore, light influences the physiological activity of IAA while synthetic auxins are not as light sensitive.

Hormone Balance

Auxin		**Cytokinin**
High		Low
↕	Root formation on cuttings	↕
	Embryogenesis	
	Adventitious root formation in callus	
	Callus initiation	
	Adventitious shoot formation	
	Axillary shoot growth	
Low		High

Cytokinin by itself does not induce vascular tissues, but in the presence of IAA, cytokinin promotes vascular differentiation and regeneration. Cytokinin, which promotes cell divisions in the vascular tissues, is a limiting and controlling factor that increases the number of xylem fibers in tissue culture and along the plant axis. In tissue cultures, low IAA concentrations induce sieve elements but not tracheary elements, whereas high IAA concentrations resulted in the differentiation of both phloem and xylem. However, even in cultures grown at a high IAA concentration, only phloem developed at the surface further away from the high auxin-containing medium. Abscisic acid, ethylene, gibberellins, and other hormone-like compounds have regulatory roles which cannot be ignored in tissue culture. For instance, although abscisic acid, ethylene and gibberellins are not added to cultured cells to ensure organogenesis or cell proliferation, these hormones are synthesized in the tissues and are playing an active, but hidden role in growth and development of the plant tissues.

Plant hormones do not function in isolation within the plant body, but, instead, function in relation to each other. Hormone balance is apparently more important than the absolute concentration of any one hormone. Both cell division and cell expansion occur in actively dividing tissue, therefore cytokinin and auxin balance plays a role in the overall growth of plant tissue.

Interesting facts:

- The first plant hormone to be discovered is Auxin.
- The first cytokinin to be discovered was the synthetic analog kinetin.
- Ethylene is also known as ‘ripening hormone’ or ‘death hormone’.

Questions:

9. What are plant growth hormones? Give examples.
10. ________ is the first plant hormone to be identified.
    (a) Auxin
    (b) Gibberellin
    (c) Cytokinin
    (d) Abscisic acid
11. Draw the structure of auxin.
12. What are natural auxins? Give examples.
13. What are synthetic auxins? Give examples.
14. Give an example of natural and synthetic cytokinin.
15. ________is known as the ‘ripening hormone’.

(a) Abscisic acid

(b) Auxin

(c) Ethylene

8. What are plant growth hormones? Describe each of the phytohormones in detail.

9. What are auxins? How can auxins be classified based on its occurrence in plants? Add a note to it.

10. How was gibberellin discovered? Mention the functions of gibberellin.

12. Discuss the effect of cytokinin in plant growth and development.

13. Discuss the effect of abscisic acid in plant growth and development.

14. Which plant hormone is known as the ‘ripening hormone’? How was it discovered? Discuss its effect in plant growth and development.

References:

- Taiz, L. and Zeiger, E. (2002). Plant Physiology. Sinauer Associates. 5: 423-556.
- Cooper, G. M. (2009). The Cell: A Molecular Approach. 5 edition. Sinauer Associates. 15: 608-09
- Gaspar, T.; Kevers, C.; Penel, C.; Greppin, H.;. Reid, D. M., Thorpe, T. A. (1996). Plant Hormones and Plant Growth Regulators in Plant Tissue Culture. In Vitro Cell. Dev. Biol.--Plant3 2:272-289.