1 PLANT GROWTH AND DEVELOPMENT

You must have noticed that all living organisms grow in size. But have you ever thought how a do they grow? Growth takes place due to cell division, which increases the number of cells in the body. This process continues and we observe increase in weight, size and volume of all plants and animals. This is called growth.

Growth *in living organisms may be defined as an* ***irreversible increase*** *in the* ***number*** *and* ***size*** *of a* ***cell****, organ or whole organism.*

Growth in living organisms is not uniform throughout the life span. Growth takes **Heredity** place at a **faster** rate till the plants or animals **attain maturity**. Then it **slows down** and at a particular time it **stops**. Later in life **death** occurs. All these changes that occur in an organism starting from its beginning till its death may collectively be termed as **development**.

Development *is associated with* ***morphogenesis*** *and* ***differentiation****.*

Morphogenesis is the process of development of **shape** and **structure** of an organism; and

Differentiation is the process of change in cells, tissues or organs to carry out different **functions**.

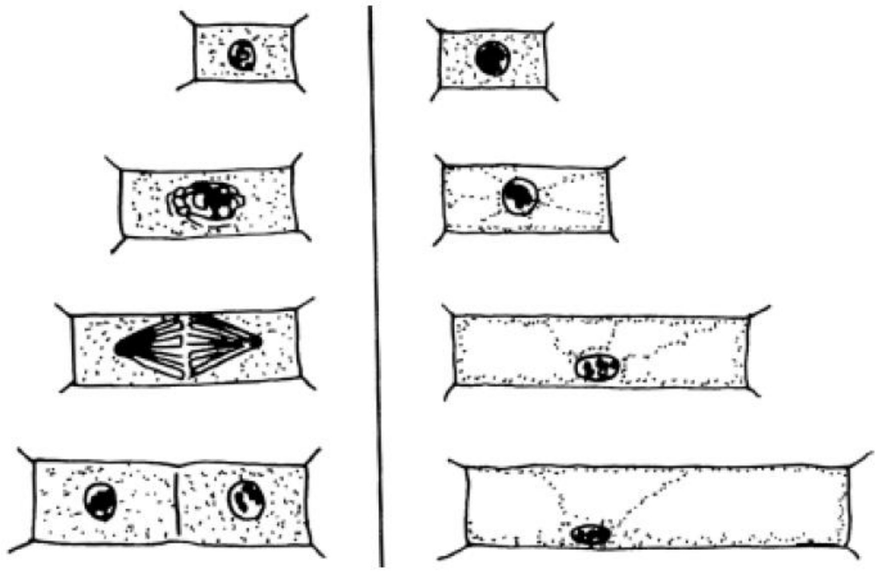
Development *is the whole series of* ***qualitative*** *and* ***quantitative*** *changes such as growth, differentiation and maturation, which an organism undergoes throughout its life cycle.*

1.1 Stages of Cellular Growth

You have already learnt that growth of an organism is always associated with growth in **size** and **number** of cells. The growth of an organ or an organism occurs in three successive stages:

1. **Cell division**: The number of cells increases due to mitosis.
2. **Cell enlargement**: The **size** of individual cell increases after cell division due to increase in the volume of its protoplasm.
3. **Cell differentiation**: In this stage, structure of the cells changes to perform specific functions. And similar type of cells having same functions form a group, which is known as tissue.

In lower organisms such as **bacteria** and **algae** the **entire body grows**. But in **higher organisms** like ferns, pine and flowering plants, growth is restricted to the cells present only in the growing regions, like **shoot apex** and **root tip** and close to the **lateral sides** of the stem and root. Growth at the tips leads to **elongation** of body parts and **lateral** (sideways) growth leads to increase in the **thickness** of stem and root.



(a) Cell Division (b) Cell Enlargement

1.2 Types of Plant Growth

1. **Primary and Secondary Growth:** The meristematic cells present at the root and shoot apices divide mitotically and increase the **length** of the plant body. This is known as primary growth. Secondary growth is referred to as the increase in the **diameter** of the plant body by the division of the secondary meristem.

2. **Unlimited Growth:** When the plant constantly grows from the **germination** stage to **death**, it is called unlimited growth.

3. **Limited Growth:** In this stage, the plant parts **stop growing** after attaining a **certain size**.

4. **Vegetative Growth:** It involves the production of stem, leaves, and branches, except the flowers.

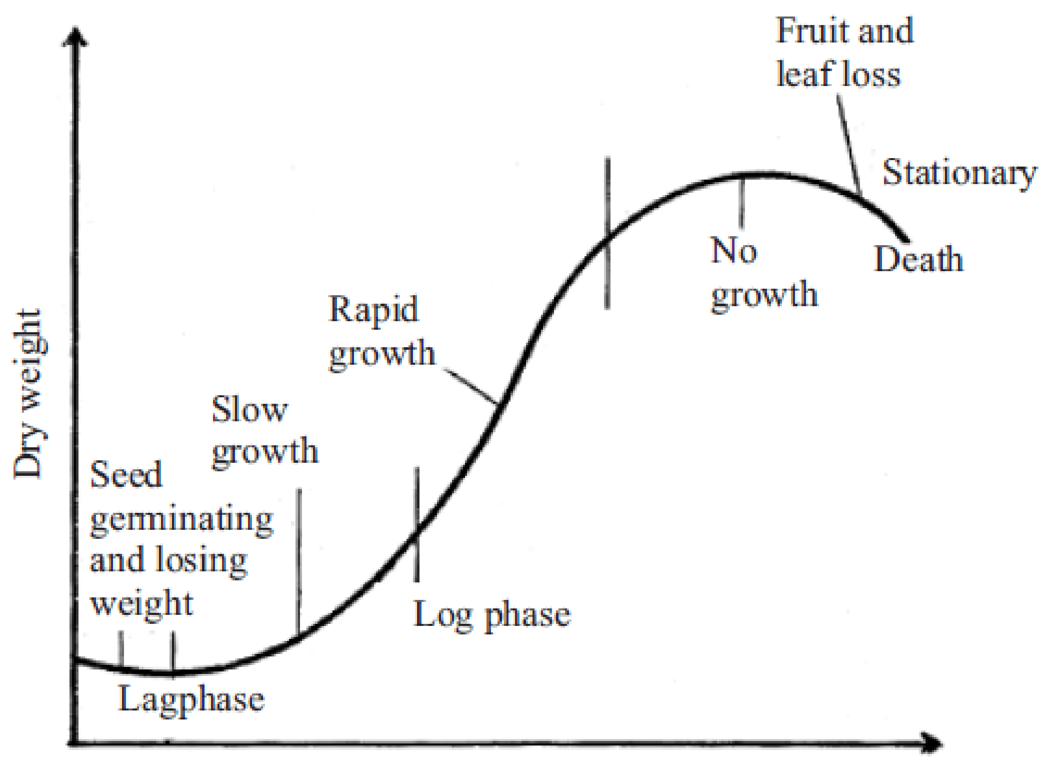
5. **Reproductive Growth:** Flowering occurs at this type of growth stage.

1.3 Growth curve

The rate of growth of a plant or plant part is **not always the same** during its life span. Sometimes it is slow and at other times rapid. If we plot the increase in cell number (growth rate) against time, a typical S-shaped curve is obtained. This is called growth curve or sigmoid growth curve.

This curve has three phases of growth.

- **Lag Phase** – This is the initial phase of growth when the rate of growth is very slow.
- **Log Phase** – It shows rapid growth and maximum during the entire life span.
- **Stationary Phase** – Here the rate of growth starts decreasing and finally it stops.



The total time period during which the fastest growth of the organ or organism occurs is called **grand period of growth**.

1.4 Measurement of Growth

After knowing the different phases of growth let us know how to measure growth in plants. Growth in plants being a quantitative phenomenon can be measured in relation to time. It can be measured in terms of:

- Increase in **length** or growth – in case of **stem** and **root**;
- Increase in **area** or volume – in case of **leaves** and **fruits**;
- Increase in the **number of cells** – in **algae**, **yeast** and **bacteria**.

1.5 Factors Affecting Plant Growth:

Generally, plant growth is influenced by a number of factors both **external** and **internal**.

1.5.1 External growth factors:

External factors are those factors present in the **environment** that affect the growth of the plants directly or indirectly. These factors are; Light, Temperature, Water, Mineral nutrients.

1.5.1.1 Light

You have already learnt about the necessity of light for the process of **photosynthesis**. Besides photosynthesis, light is also essential for seed **germination**, **growth** of seedling, **differentiation** of various tissues and organs, and **reproduction**.

When plants grow in dark, they become tall, yellowish and weak, and the Heredity leaves are very small.

1.5.1.2 Temperature

Some plants grow in **cold** climate and some in **hot** climate. The **optimum** temperature required for growth of plants ranges between **28-30°C**, but it may occur in the temperature range of **4-45°C**. All metabolic activities of plants are directly affected by variation of temperature.

A very low temperature causes injuries to the plant due to chilling and freezing, and very high temperature stops its growth.

1.5.1.3 Water

You have already learnt that a plant absorbs water by its roots, uses it in **photosynthesis** and other **biochemical** processes and some of it is lost through **transpiration**. For proper growth of plants, a particular quantity of water is required.

Both deficiency and excess of water retards the growth of plants.

1.5.1.4 Mineral Nutrients

Just like human beings, plants require proper nourishment for their growth and development. All metabolic processes require **inorganic nutrients**. Soil nutrients are divided into **macronutrients** and **micronutrients**. Nitrogen, potassium, calcium, magnesium, sulfur, and phosphorus are the macronutrients required by the plants. The micronutrients include iron, copper, etc.

Deficiency of these nutrients in plants makes them prone to several diseases. Even if a single nutrient is lacking, it results in stunted growth of the plant.

1.5.2 Internal Growth Factors

In addition to the external factors as discussed above, there are some substances produced in the plant body itself, which affects the growth of the plant. These are called plant hormones or **phytohormones** or **growth hormones**.

1.6 Internal growth factors

In the higher plants, the **regulation, coordination of metabolism, growth**, and morphogenesis efficiently depend on **chemical signals** produced by the plant **itself**. In the **19th** century many of our current concepts about intercellular communication in plants were derived from **research conducted in animals** and hence the analogy of some terms and concepts. In animals the chemical messengers mediating intercellular communication are called hormones (**Greek Hormaein= to stimulate**), whereas in **plants**, growth and other physiological functions are mediated by **chemical messengers** called plant hormones or **phytohormones**. The term phytohormone is strictly used to name the compound chemicals **synthesized inside the plant**, which can be **transferred** and used in specific physiological communication processes, not including substances of **xenobiotic** origin (typically a synthetic chemical, that is foreign to the body). However, the terms plant growth regulators and phytohormone are sometimes often used **analogously**. Plants can generate phytohormones that regulate ***shoot growth, root growth, flowering, leaf abscission, fruit ripening***, and many other metabolic processes. In general, the most important hormones used in vegetative propagation of plants are Auxins (**AUXs**), Cytokinins (**CTKs**), Gibberellins (**GBRs**), Abscisic acid (**ABSAc**), and Ethylene (**ETH**), which promote root growth, cell growth, and stem elongation, among others. However, through science and technology progress, **new chemical compounds** exhibiting the properties of plant hormones have been discovered in recent years. Besides natural phytohormones, it is possible today to find **synthetic and biotechnological commercial products**, referred as **plant growth regulators**, which are well known for their regulatory effects.

Thus, plant growth stimulators are ***synthetic, biological, biosynthetic substances, or systems, able to produce an effect on plants;*** some examples are naphthalene acetic acid, or **ANA**, which is a **root growth promoter** and **bacterial inoculate able to contribute with the nitrogen fixing and the strengthening of the rhizosphere**.

The uses of these chemical compounds in the development of the **agricultural industry** are of **great importance to food security**, the stable supply of agricultural products and the subsequent employment generation; in this regard, the global plant growth regulators **market size**, including auxins and cytokines, was estimated to be valued at **$5.72 billion** in **2019** and is assumed a **compound annual growth rate** of **8.5%** during **2020 to 2027**, mainly in **fruit and vegetable crops, oilseeds, cereals, legumes**, among others.

Moreover, in **recent years** there has been a growing interest on the part of **medicinal chemistry for biological activity** of **small molecules on plants**, including some plant hormones, in **search of new areas** of economic and scientific development. In this way, due to their origin, structural richness and their natural influence on biological processes, the knowledge of these biochemical entities and their properties, phytohormones, plant growth regulators, and plant-signaling molecules are a promising alternative to advance in the development of more sustainable strategies for the production of food, goods and services. By the above, it is important to advance toward the knowledge of these substances, design new strategies and approach for expanding their potential uses.

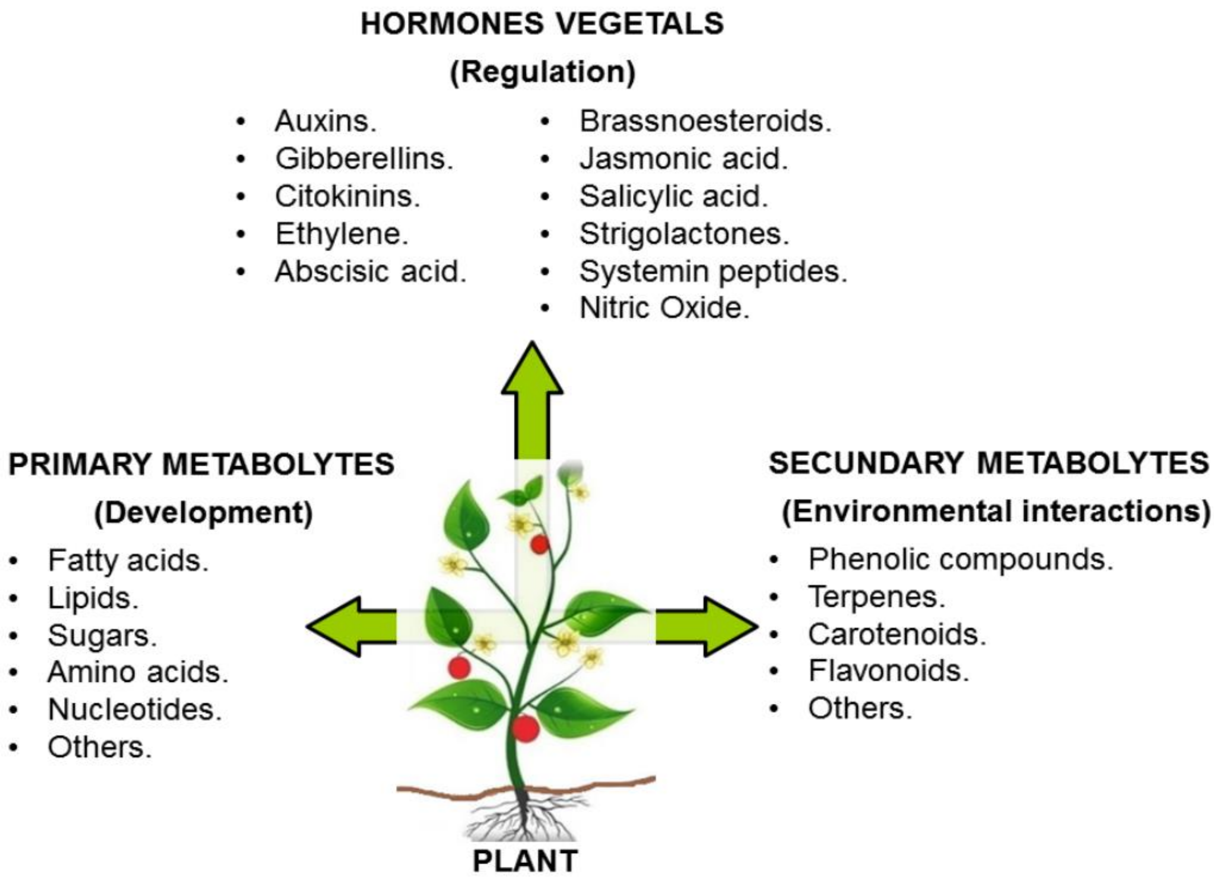
1.7 Metabolic regulators of plants

Different physiological processes (**metabolism**) of plants such as **nutrition**, **absorption**, **circulation**, **transpiration**, **photosynthesis, respiration, growth, flowering, fruit ripening, rooting**, among many others, are in fact a varied and **complex process** of **chemical reactions** and **physical events**. Plants are always adapting to their environment in order to ensure their survival and viability. In these pathways and gradients, chemical messengers play an important role in growth, stress response and homeostasis. **Within the metabolism of plants, diverse groups of chemical compounds can be identified**, classified according to their function as: primary metabolites, secondary metabolites and plant hormones.

1. **Primary metabolites** are **directly related to growth and they are conserved by the plant** (e.g., amino acids, nucleotides, sugars, lipids, fatty acids, among others).

2. **Secondary metabolites** include a wide number and variety of compounds with a wide structural richness such as phenolic compounds, terpenes, and nitrogen-containing chemical groups like alkaloids, which are **produced at very low concentrations.** These substances emerge from biochemical processes which are **not directly related with the survival of the plants**, for this reason, it is accepted that their production is associated to one “secondary metabolism” and in this way to differentiate it from those metabolic processes essential for the life of plants.

3. **Plant hormones** are **secondary metabolites**, which can be defined as **small molecules that regulate plant processes**, including the **production of other *metabolites***, by **interacting with receptor proteins**, leading the coordination of **physiological processes inside and outside the cells and tissues.**



1.8 Plant growth regulators

Plant growth regulators, or **phytoregulators**, are chemical compounds acting as plant-originated **bioregulators** able to **produce effects similar** to those caused by **phytohormones.** They are **exogenous** sourced through and their supply is specific purposeful that is usually related to productive goals. In agriculture, regulators can promote plant development and productivity:

1. Stimulate rooting of cuttings,
2. Inhibit seed dormancy,
3. Promote flowering,
4. Accelerate or delay fruit ripening,
5. Control plant development,
6. Increase branching,
7. Suppress shoot growth; for example, in weed management for crops,
8. Harvest,
9. Reforestation,
10. Phytoremediation activities,
11. In vitro testing, among many other purposes.

Note that the **main difference** between the concepts phytohormone and phytoregulators is the **xenobiotic origin of the latter**.

Therefore, strictly speaking, if a **phytohormone is synthesized, either by chemical or biotechnological methods**, and subsequently used to promote a response different from that which is naturally expected from its biosystem of origin, the most appropriate name for this biomolecule is **Phyto-regulator** (for an effect on plants) or bioregulator (for an effect on the metabolism of living organisms). Thus, it is understood that the **phytohormone concept is limited** to a specific context, while the **Phyto- regulator** and bioregulator concepts are **broader in their meaning**.

Type	Phytohormones	Plant growth regulators
Description	This term describes chemical substances **synthesized by the plants** themselves in order to perform diverse functions related to growth and development of plants.	These are **artificially synthesized** chemical compounds, mainly used in agriculture, able to promote the development and productivity of crops.
Typical application	Interruption of the latency period of seeds, induction of fruit development, regulation of longitudinal growth the stem, regulation of photosynthesis, senescence, apoptosis (programmed death), resistance to pathogens, among others.	For agricultural purposes, they are usually used as **maturation accelerators**, growth **stimulators** and **inhibitors**, **flowering**, among others.
Example	Auxin, Gibberellin, Cytokinin, Abscisic acid, Ethylene, Brassinosteroids, Jasmonic acid, Salicylic acid.	Naphthalene Acetic acid, Indolbutyric acid, Ethephon, Chlormequat chloride.

1.9 Phytohormones

Unlike hormones of **animals**, in plants there are **no specialized sites** or organs for **biosynthesis** of phytohormones, therefore, these can be generated **anywhere**. It is now known that plant development is regulated by the following groups of phytohormones: **AUXs**, **GBRs**, **CTKs**, **ETH**, and **ABSAc** usually referred as the classical phytohormones. In addition, other signaling molecules with similar activities to plant phytohormones have been identified that play an important role in **disease resistance and defense against** herbivores such as brassinosteroids (**BRSTs**), jasmonic acid (**JMAc**), salicylic acid (**SLAc**), strigolactones (STGLs), systemin peptides, and nitric oxide (**NO**). Even though **NO** is considered an **important signaling molecule**, and **intermediary in metabolic** processes by many scientists, is still **not recognized as a phytohormone** simply because it is an

inorganic compound. Nevertheless, the **number of phytohormones** and messenger agents within plants will **surely continue increasing** as knowledge expands and researchers can build consensus on new evidence and understanding of the chemical reactions occurring within plants.

Almost **all phytohormones** have been found in **sieve elements** and it is believed that this is where long-distance transport occurs. Besides, transport between different plant organs is important because these chemical messengers can signal to one organ the status of the other, generally by pathways based on transportation through **phloem** and **xylem**; for example, **buds produce** growth regulators such as **AUXs**, which can be rapidly **transported** to the **roots** via the **phloem**, whereas **roots** produce **CTKs**, which are **translocated to the buds** via the **xylem**. Another form of transport of various hormones, which are **weak acids**, is the diffusion of them across cell membranes when they are in their protonated form.

The primary site of action of plant growth hormones at the molecular level remains unresolved.

Reasons

• Each hormone produces a **great variety** of physiological responses.

• Several of these **responses** to different hormones frequently are **similar**.

• The **response of a plant or a plant part** to plant growth regulators may vary with the variety of the plant.

• Even a single variety may **respond** differently depending on its **age**, **environmental** conditions and **physiological** state of development (especially its natural hormone content) and state of nutrition. There are always exceptions for a general rule suggesting the action of a specific growth regulator on plants.

• There are **several proposed modes of action** in each class of plant hormone, with substantial arguments for and against each mode.