Université de Ain Temouchent –Belhadj Bouchaib
Faculté des Sciences et de la Technologie

Département d'Agroalimentaire

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Titre

Physiologie végétale

Cours destiné aux étudiants de
Niveau : **Licence 2**
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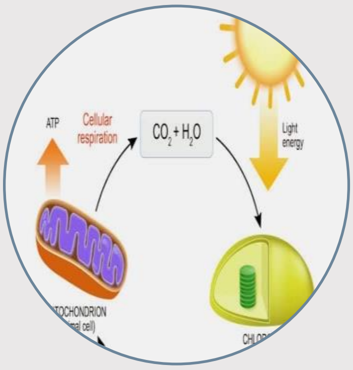
Belhadj Bouchaib

PLANT PHYSIOLOGY



University of Ain Temouchent
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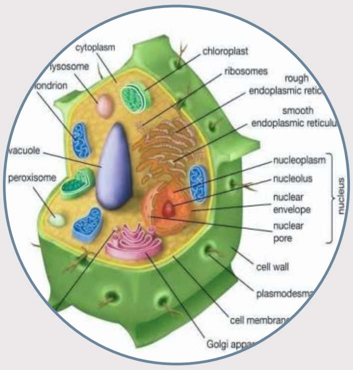
Pedagogical handout



LICENSE 02/ ECOLOGY AND ENVIRONMENT

2023-2024

FOREWORD

Plant physiology is a fascinating discipline that examines the roles and mechanisms of plant life. It examines how plants interact with their environment, how they develop, reproduce and adjust to changing conditions.

The aim of this course is to provide a good understanding of the physiological mechanisms that govern plant life, focusing on essential elements such as photosynthesis, transpiration, germination, growth and fruiting.

Plants play a vital role in our environment, generating the oxygen we breathe, forming the basis of the food chain and regulating the climate. Understanding their physiology is therefore essential not only for researchers, agronomists and ecologists, but also for anyone interested in the preservation of biodiversity and sustainable development.

During this program we will study fundamental concepts, practical experiments and case studies that highlight the importance of plant physiology in different fields, such as agriculture and ecology. We hope this course will spark your interest and encourage you to discover more about the captivating world of plants.

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(Mechanism of water absorption and transit

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Introduction :

In plant biology and ecology, plant physiology is an essential discipline that focuses on the mechanisms and processes that govern plant function. As autotrophic organisms, plants play an essential role in terrestrial ecosystems, providing oxygen and forming the backbone of the food chain. Understanding plant physiology is essential to understanding how plants adapt to their environment, how they develop and how they interact with other organisms.
This plant physiology course will cover a variety of important topics, such as:
1. The organization of a plant is defined by the collaboration of two systems (root and aerial) to ensure the growth, development and survival of the plant in its environment.
2. The organization of a plant cell is based on several essential elements, each with specific functions.
3. Water nutrition refers to all the processes by which plants absorb, transport and use water, an essential element for growth and life.
4. Transpiration is the evaporation of water from plant surfaces, mainly leaves, and plays an essential role in regulating water supply and plant temperature.
5. Mineral nutrients: The uptake and use of essential nutrients by plants, and their impact on plant health and growth.
6. Nitrogen nutrition refers to all the mechanisms by which plants absorb and use nitrogen, a fundamental element for their growth and development.
7. Carbon nutrition refers to the absorption and utilization of carbon by plants, an essential element for their growth and development.
8. plant hormones are chemical compounds that control various physiological processes, such as growth, flowering and response to stress.
9. Development and reproduction: The processes that govern the life cycle of plants, from germination through growth and completion to reproduction.
10. Photosynthesis is the process by which plants convert sunlight into chemical energy, which is essential for their development and the production of food.

This course covers not only theoretical concepts, but also the experimental methods used to study plant physiology. Through case studies and practical applications, we will highlight the importance of plant physiology in various fields, including ecology and biodiversity conservation, agronomy, food science and biotechnology.

Plant physiology offers a dynamic, interdisciplinary approach that enables us to deepen our understanding of the plant world and its role in our environment. We invite you to join us on this adventure and explore the splendors of nature.

Course objective

This course enables students to acquire a general knowledge of plant systematics (the importance of classification), to understand species and their identification, to understand the evolution and classification of the plant kingdom, and to develop their sense of observation, which is one of the essential foundations of the biologist's, agronomist's and ecologist's approach.

Part 1. Nutrition

Part 1 Nutrition

1-Remind the basics

1.1 Organization of a plant

1.2 Organization of a plant cell

2-Water nutrition (mechanism of water absorption and transit).

3-Transpiration and water balance

3.1 Demonstration

3.2. Location and measurement

3.3. Variation in transpiration

3.3.1 Influence of plant morphology

3.3.2 Influence of environmental factors

3.4. Physiological determinism of transpiration

3.5. Plant water balance

3.6 The importance of transpiration for plants

4. mineral nutrition (macro and trace elements)

5. nitrogen nutrition (nitrogen cycle, nitrate transport and assimilation)

6. carbon nutrition (photosynthesis).

Chapter 1 : Reminder of basic concepts

Chapter 1 : Reminder of basic concepts

Introduction :

A plant is an autotrophic living organism, typically anchored to the soil by its roots, meaning it cannot move to feed or reproduce. Plants exist at the intersection of two environments: the air and the soil. These environments are dynamic and change due to factors such as the time of day, weather, seasons, and the presence of predators. Throughout evolution, plants have developed specialized processes and systems that enable them to perform their essential functions, such as growth, reproduction, and survival.

1.1 Plant Organization

Plants are organized into two main systems: the aerial system and the underground root system. The aerial system includes the reproductive organs (flowers and seed-bearing fruit) and the vegetative organs (stems and leaves, including the leaf blade and petiole). The underground root system is made up of branched roots that anchor the plant and aid in the absorption of water and nutrients from the soil.

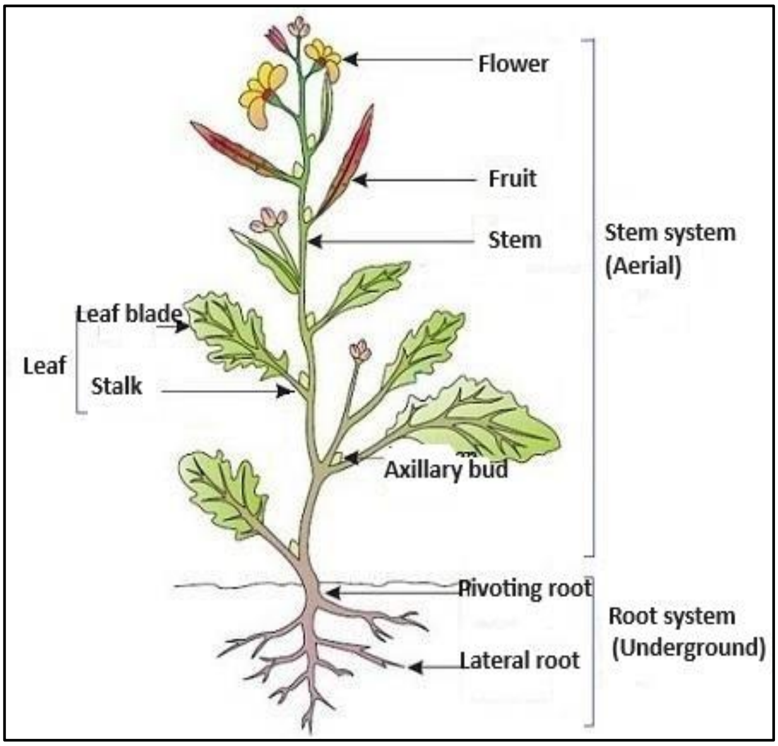

Figure .1. Diagram of the basic morphology of a flowering plant

1.1.1. Root

The root is a subterranean, non-chlorophyllous structure with endogenous branching, whose function is to anchor the plant and absorb water and dissolved minerals. The following zones can be observed from top to bottom:

- **The Collar:** The area between the root and the stem, usually at ground level.
- **The Growth Zone (Suberous Zone) :** Located just above the root hairs, this is where new lateral roots appear.
- **Root Hairs:** These absorb water and minerals dissolved in the soil.
- **The Elongation Zone :** Located between the root cap and the piliferous zone, where the root elongates.
- **Meristematic Zone :** Found at the root tip, this zone contains actively dividing cells.
- **The Root Cap :** A structure that completely covers the root tip. It facilitates root growth and protects the new underlying tissue.

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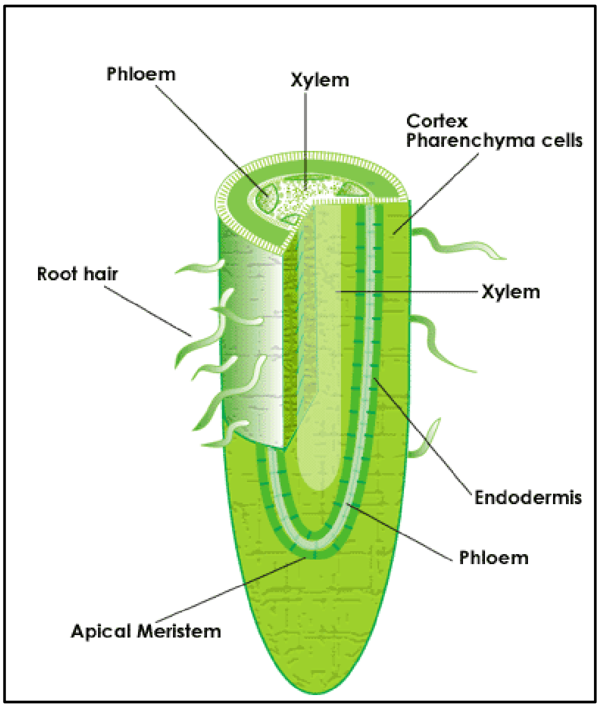

Figure.2. Root structure

1.1.1.1.The Different Types of Roots : There are three types of roots:

- **Taproots :** Characterized by a large, vertical main root that branches into numerous secondary roots. This type of root system firmly anchors the plant to the soil, helping it resist the forces of wind, gravity, and runoff.

- **Fasciculated Roots :** Composed of several similar-sized roots that develop close to the soil surface, providing the plant with a stable foothold and protecting it from erosion. This type also offers a large surface area for contact and exchange with the soil.
- **Adventitious Roots :** These roots form on non-root tissues, such as stems (either subterranean or aerial), like stolons. Adventitious roots are often used for plant propagation and cuttings.

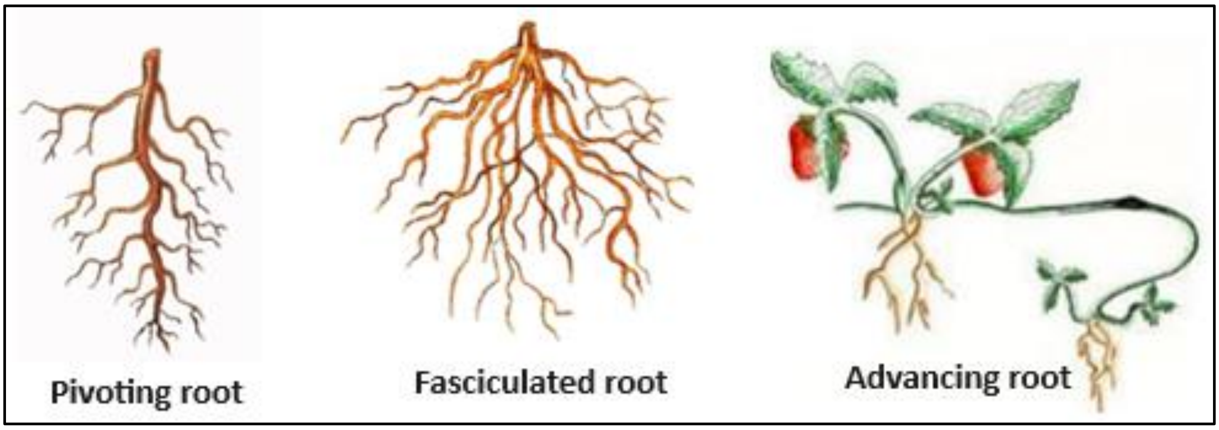

Figure.3. The different types of root

a).Adaptive Root Diversity

Roots do more than just anchor plants in the soil and absorb water and mineral salts. The root system also performs various adaptive functions due to specific modifications, which help plants survive in diverse environments:

- **Hypertrophied Roots of Root Tubers:** In biennial species such as carrots and beets, these enlarged roots store nutrients, allowing the plant to survive unfavorable seasons and resume vegetative growth when conditions improve.
- **Adventitious Roots of Ivy :** These fine, numerous roots enable ivy to cling firmly to walls and trees, providing strong support for climbing.
- **Pneumatophores of Mangroves :** These specialized roots grow upwards (negative geotropism) and emerge into the air, allowing the plant to absorb atmospheric oxygen in waterlogged and oxygen-poor soils.
- **Stilt Roots in Mangroves:** Many mangrove plants develop stilt-like aerial roots to provide support and prevent sinking in unstable, shifting substrates.
- **Buttress Roots of Large Tropical Trees:** These tall aerial roots grow from the base of the trunk and help stabilize large trees in shallow soils, providing additional support.
- **Sucking Roots of Parasitic Plants :** These roots are adapted to penetrate host plants and absorb nutrients from them.

- **Chlorophyll Roots of Epiphytes :** Many epiphytes, such as tropical orchids, have green, photosynthetic roots covered with a velamen layer that absorbs rainwater and nutrients from the air.
- **Succulent Roots:** These roots are adapted to store water, helping plants survive in arid conditions.

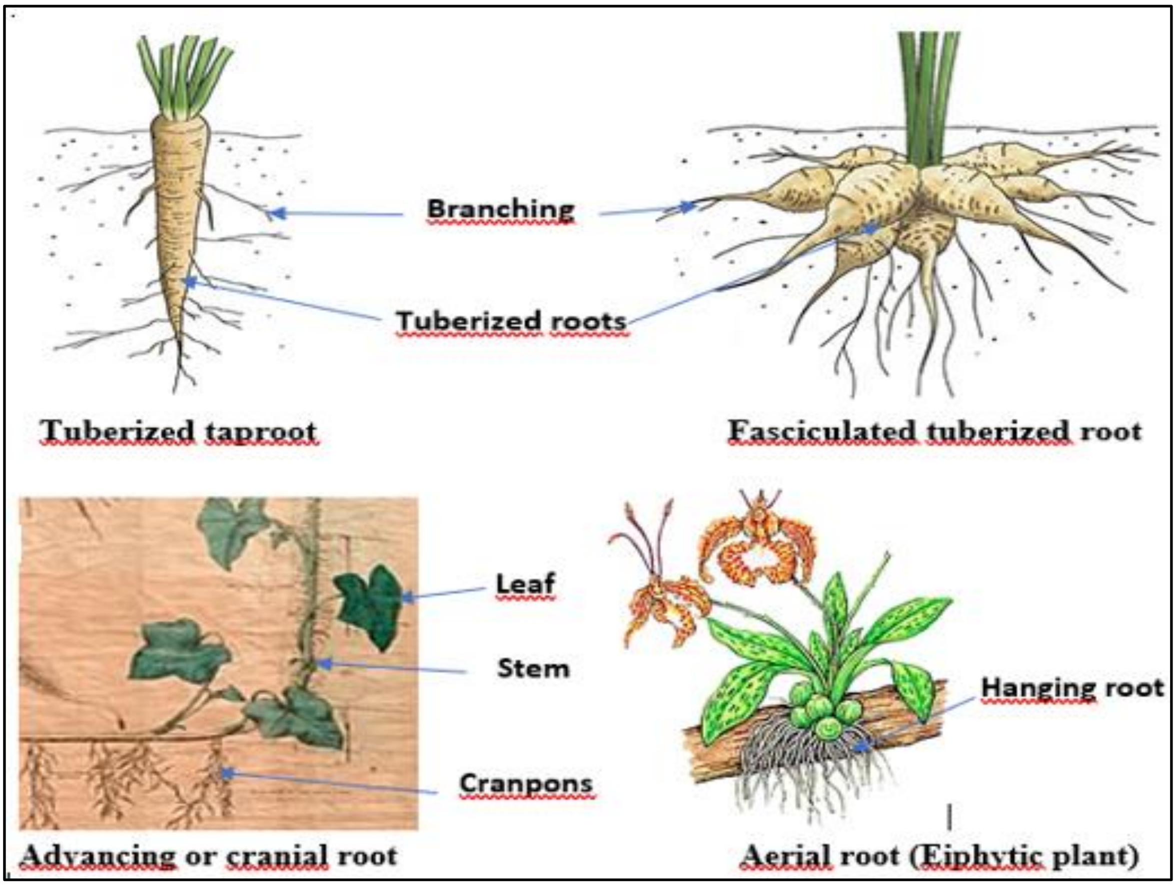

Figure .4. Modified roots

1.1.2. Stem

The stem is an organ composed of a series of internodes separated by nodes where the leaves are attached.

1.1.2.1.Stem Organization

The stem is generally the aerial part of the plant axis, supporting leaves and reproductive organs (during reproduction). It is an extension of the root system, with the **collar** being the point where the root and stem connect.

The main characteristic of the stem is the presence of **nodes**, which are small bulges where leaves are attached along its length. The **internode** is the segment between two consecutive nodes. The end of the stem is covered by the **terminal (or cauline) bud**, which consists of leaf primordia and protects the **apical meristem** (similar to how the root cap protects the root's apical meristem). The stem elongates and develops through the activity of the terminal bud, which simultaneously produces stem tissue and leaves. Each leaf is associated with an **axillary bud** at its base, some of which develop into secondary stems or twigs, each ending in a terminal bud.

1.1.2.2.Stem Types

- **Erect Stems :** Grow vertically upward.
- **Creeping Stems :** Have long internodes and grow either along the ground or just below the soil surface (e.g., suckers and stolons).
- **Climbing Stems :**
  - **Simple :** Often have spikes or adventitious roots that help them attach to supports.
  - **Twining (Voluble):** The plant wraps around a support.
  - **Tendrils:** Specialized organs for attachment that coil in response to touch (haptotropism). Tendrils can originate from the stem (e.g., grapevines) or leaves (e.g., Leguminosae tendrils).
- **Succulent Stems :** Found in most cacti and some Euphorbias, these stems store water to survive in arid environments.
- **Spiny Stems :** In some species, stems transform into spines, providing protection against herbivores.

1.1.2.3. Adaptive Stem Diversity

- **Rhizomes :** Horizontal, underground stems with scaly leaves and short nodes that periodically produce aerial shoots (e.g., ginger).
- **Tubers:** Swollen underground stems with closely spaced internodes compared to rhizomes (e.g., potatoes).
- **Bulbs :** Short underground stems with fleshy leaves that store nutrients (e.g., onions).
- **Aquatic Stems :** Differ from aerial stems in structure and can be fully or partially submerged in water.
- **Rosette Stems :** In some plants like lettuce, the stem is extremely short, giving the appearance that the leaves emerge directly from the root, arranged in a rosette at the plant's base.

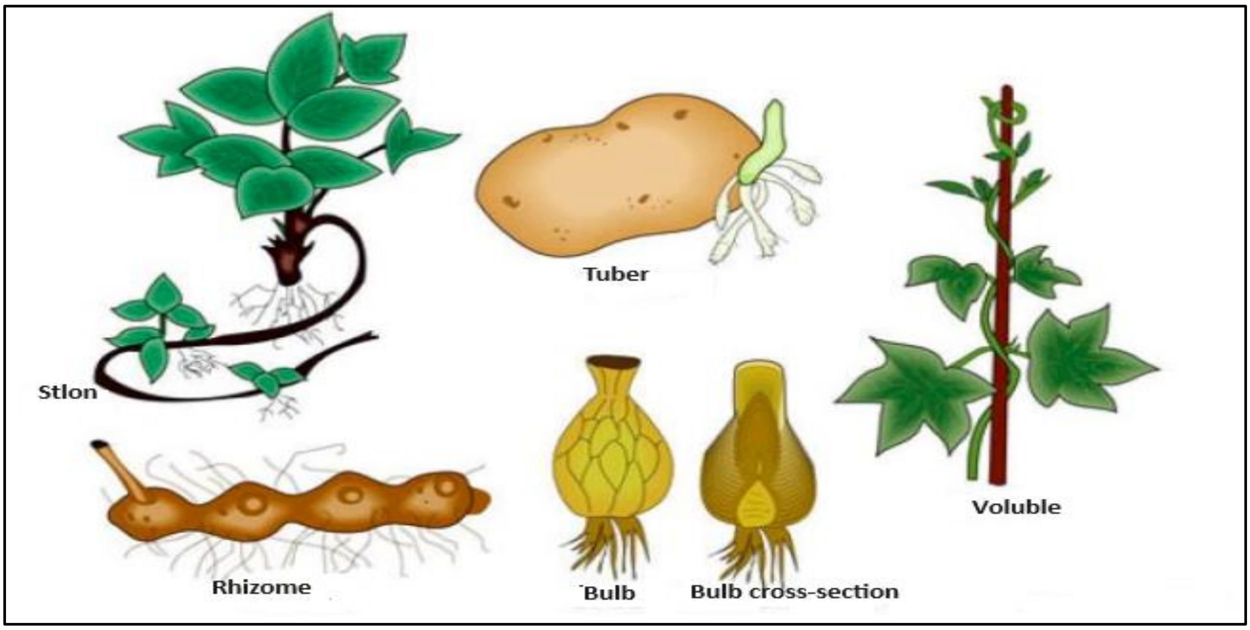

Figure .5. Modified stems

1.1.3. Leaves

Leaves are small, bilaterally symmetrical organs that ensure gas exchange with the air, playing a crucial role in photosynthesis and water regulation. They are the main organs responsible for photosynthesis, a biological process that requires light to synthesize organic matter essential for the plant's metabolism. Leaves can be categorized into two types based on their lifespan: **deciduous** (leaves last no more than one season) and **evergreen** (leaves last from 2 to 5 years).

1.1.3.1. Leaf Organization and Structure

Leaves are often flattened parts of the plant borne on lateral stems. The leafy stem forms an inseparable unit with the leaves, closely linked to the overall plant structure.

Leaves have the following components :

- **Blade (Lamina):** The flat, green part of the leaf, with two surfaces:
  - **Upper (ventral or adaxial) Side:** The side facing the top of the stem.
  - **Lower (dorsal or abaxial) Side:** The side facing the base of the stem.
- **Petiole:** The narrow stalk that connects the leaf blade to the stem at a node.
- **Venation:** The arrangement of veins within the leaf. The **main vein** (midrib) extends from the petiole into the leaf blade, where **secondary veins** branch out. There are different types of venation, such as pinnate, palmate, and parallel.
- **Stipules:** Two small leaf-like structures located at the base of the petiole, commonly found in plants like roses and legumes.

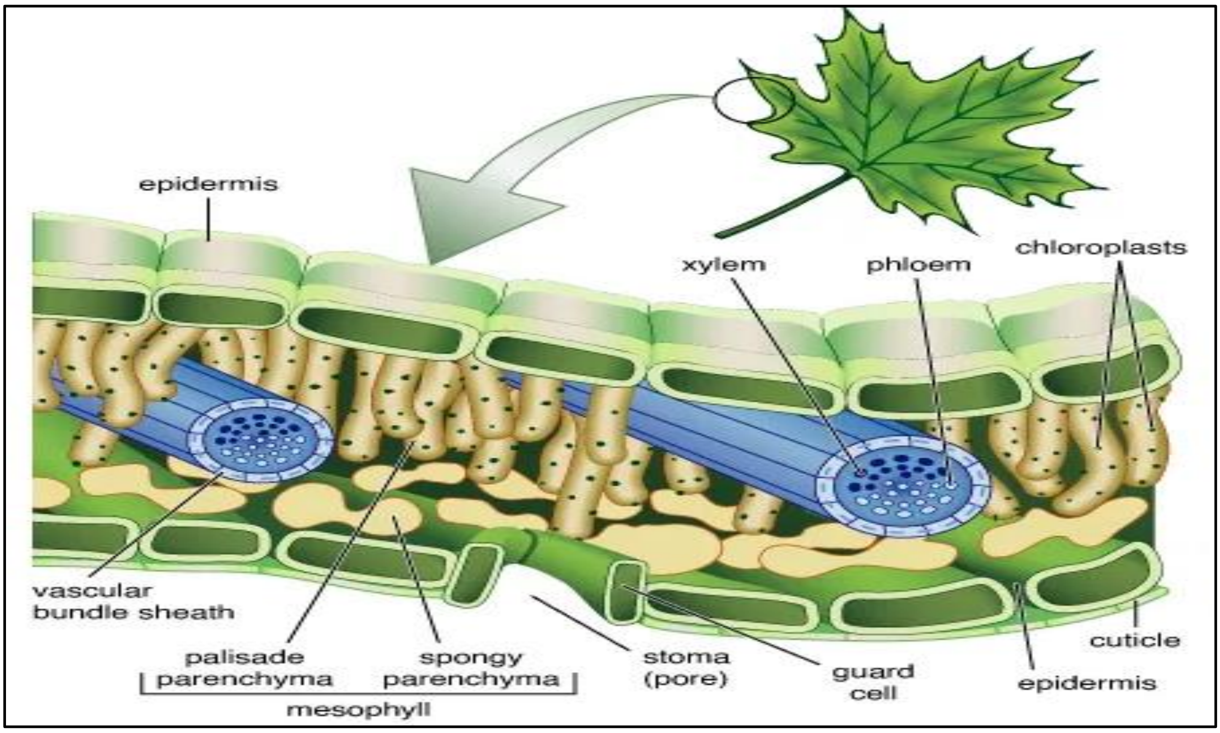

Figure.6. Sheet organization

1.1.3.2. Classification of Leaves

a).According to the Blade (Limb):

Simple Leaf: A simple leaf is characterized by a single, entire blade. Sometimes, the leaf is divided into several leaflets, with the blade then divided into several distinct parts. The blade may have entire, toothed, lobed, etc., edges.

Figure.7. Simple and compound sheets

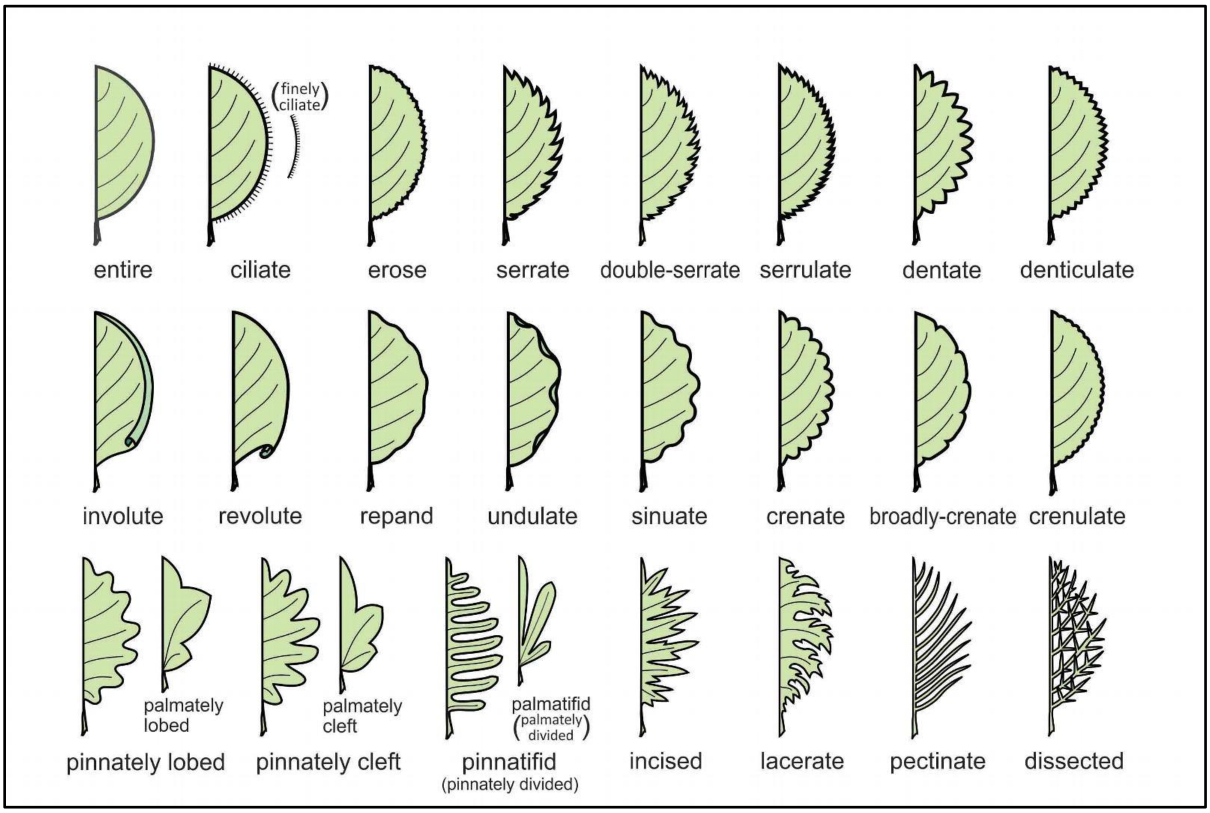

Figure.8. The different leaf margins

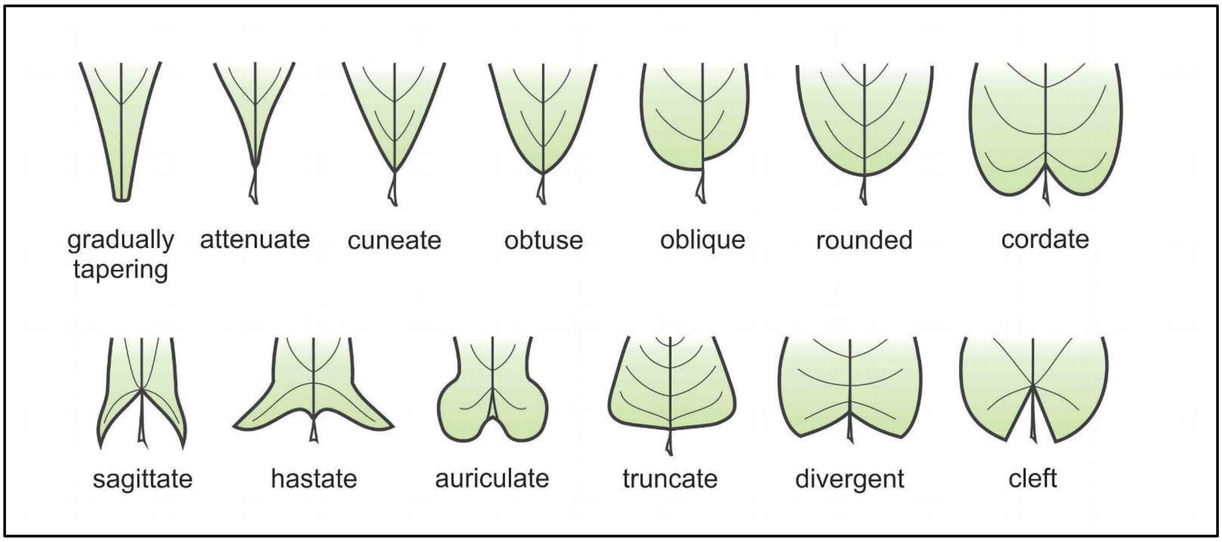

Figure .9. Leaf bases

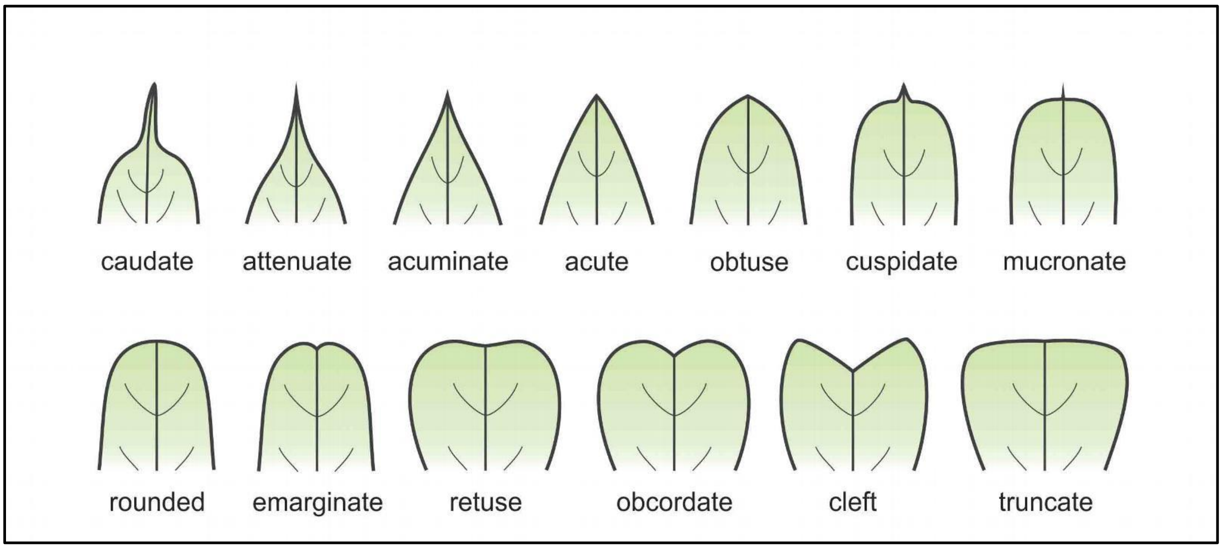

Figure .10. Leaf apices

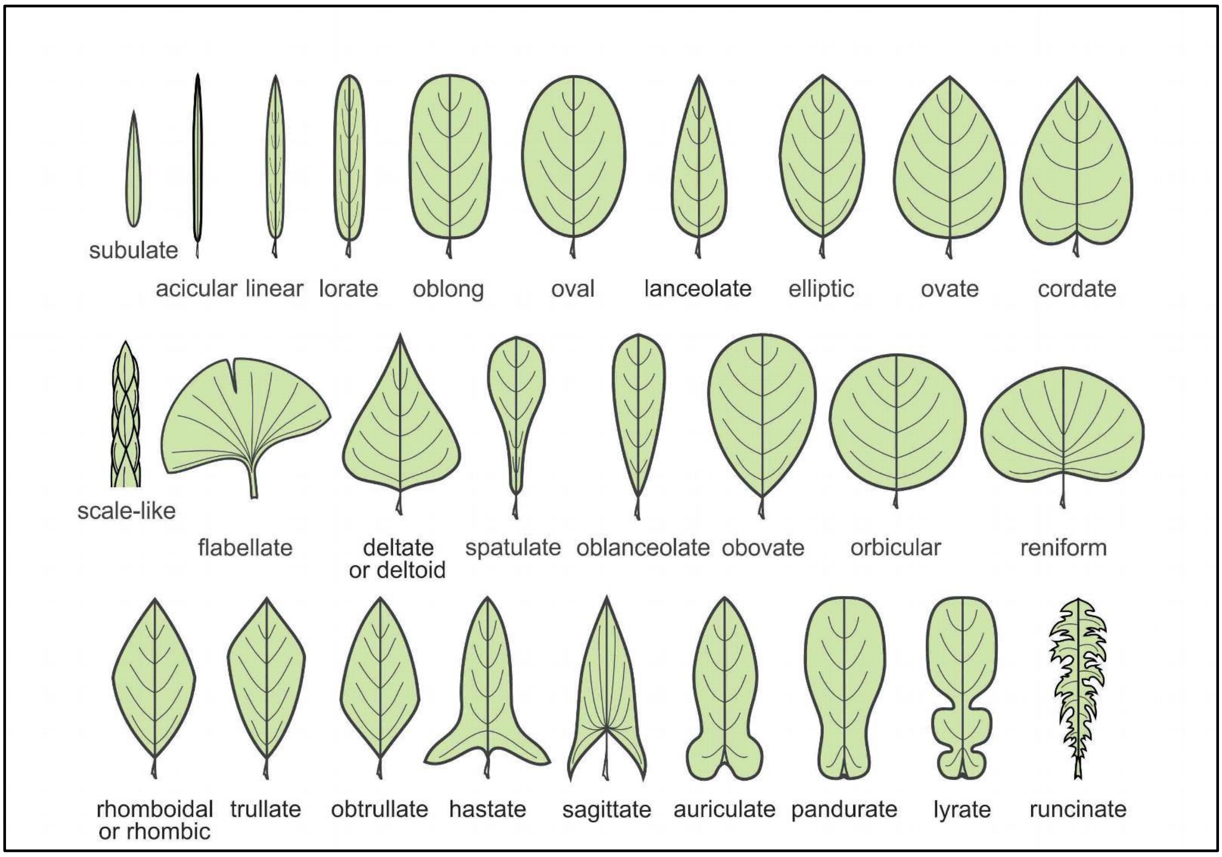

Figure.11. Basic Leaf shapes

1.1.3.3. Types of Compound Leaves

a) **Pinnate Compound Leaves**:

- **Paripinnate Leaves**: Leaflets are arranged along both sides of a common petiole, and the number of leaflets is even.

   - **Imparipinnate Leaves**: Similar arrangement as paripinnate, but with an odd number of leaflets, ending in a terminal leaflet.

b) **Bipinnate Leaves**:
   - Leaflets are further divided into smaller leaflets, making the leaf structure more complex.

c) **Tripinnate Leaves**:
   - Each leaflet is bipinnate three times, adding an additional level of division.

d) **Compound Palmate Leaves**:
   - Leaflets are attached at a single point at the apex of the petiole, resembling a hand with fingers extending from the palm.

e) **Compound Trifoliate Leaf**:
   - Composed of three distinct leaflets.

f) **Compound Pedunculate Leaves**:
   - These leaves have a petiole that divides into three petiolules, with the two lateral petiolules branching twice, each ending in a leaflet.

1.1.3.4. Modifications of Leaves for Specialized Functions

a) **Tendrils**:
   - Modified leaves or leaflets that help climbing plants attach to supports (e.g., vines).

b) **Bulbs/Fleshy Tunics**:
   - Leaves that accumulate reserves for vegetative growth after adverse conditions (e.g., onions).

c) **Water Reserves**:
   - Leaves that store water, adapted to dry, arid environments (e.g., Aloe from the Crassulaceae family).

d) **Carnivorous Plants**:
   - Leaves modified to trap insects for nutrient acquisition (e.g., Venus flytrap's jaws, Drosera's adhesive hairs, Utricularia's bladders).

e) **Spines**:
   - Leaves modified into spines to protect against herbivores (e.g., Cactus, Opuntia).

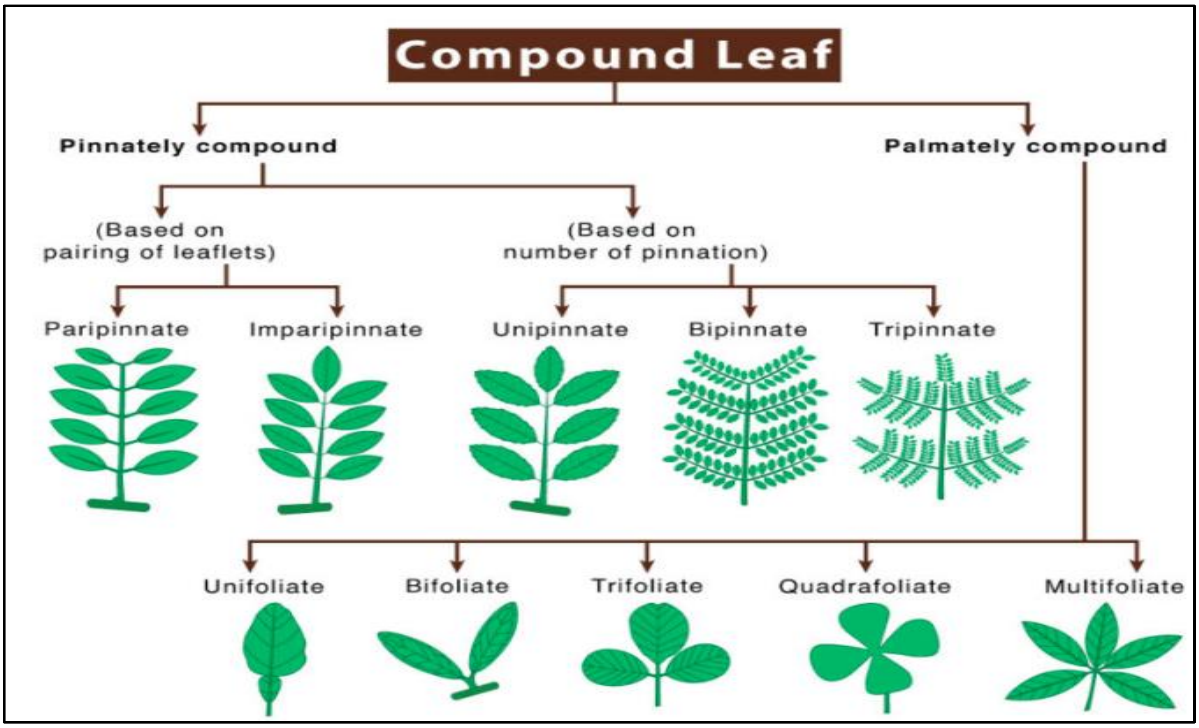

Figure .12 . The different types of compound leaves

1.1.3.5. According to veins :

Leaves are classified based on the arrangement of veins on the leaf blade, which is called venation."

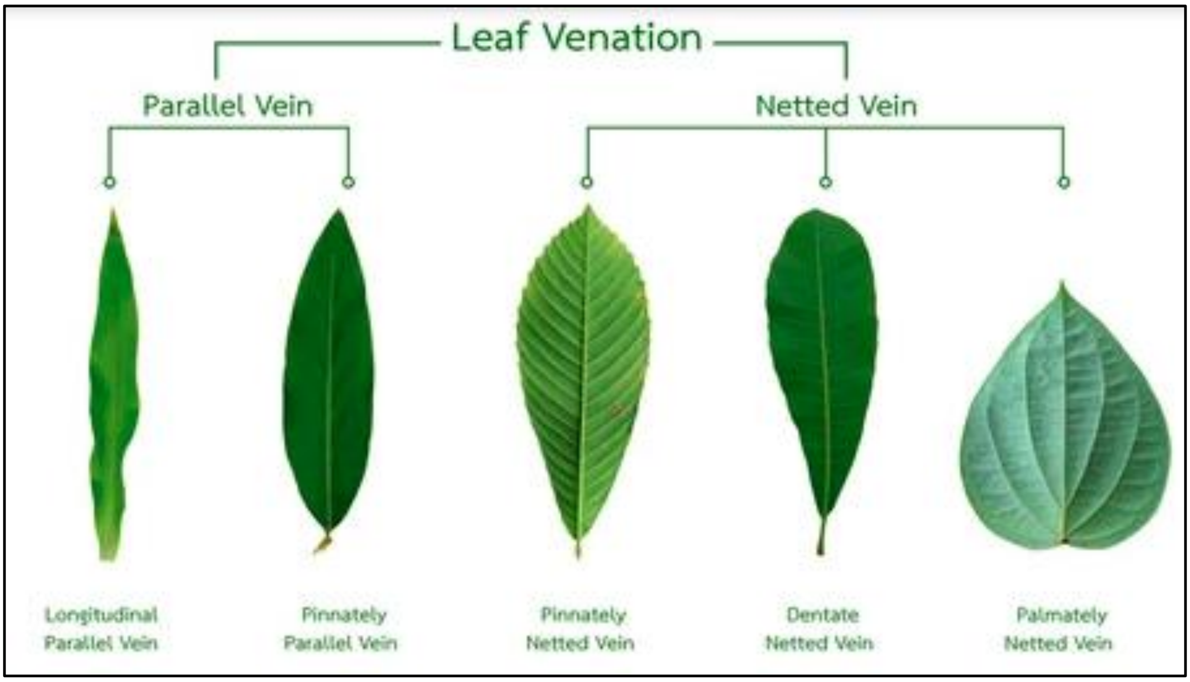

Figure.13. Leaf venation

- Uninervate leaves: with a narrow, single-ribbed blade.
- Parallel leaves: sessile, generally elongated and ribbed.

- Pinnate leaves: with a midrib or main vein dividing the leaf blade into two parts, and secondary veins.
- Palmatinervous leaves: where the petiole divides into an odd number of divergent veins, with the midrib often dominant.
- Pedate leaves: have three veins that radiate from a common point. Twigs always pointing downwards form on the two lateral veins.

1.1.3.6.Leaf-attachments

Conductive tissue irrigates the leaf blade at the veins and runs along the petiole. Leaves without petioles are called sessile. A phyllode is when the petiole is extended to the point of replacing the leaf in its function. It is possible to widen the petiole at its base to create a sheath.

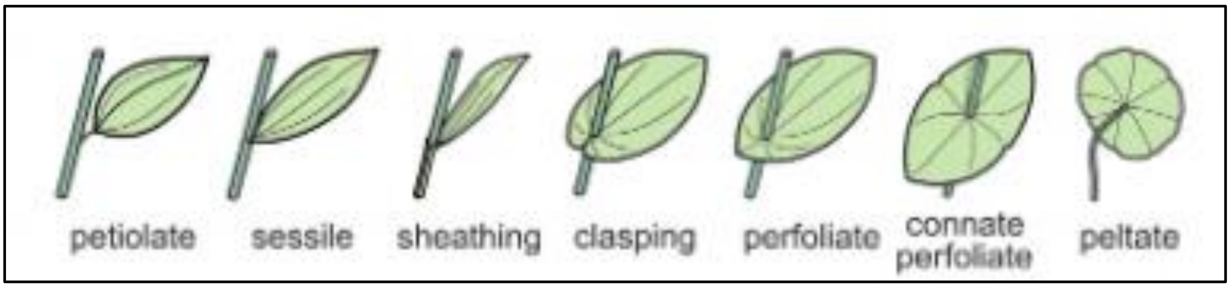

Figure.14. Leaf attachements

1.1.3.7.Phyllotaxy

The position of the leaves can vary:

- **Alternate:** a single leaf at each level (e.g., cherry).
- **Opposite:** two leaves facing each other at the same level (e.g., lilac, privet).
- **Whorled:** several leaves at each level (e.g., catalpa).

Figure .15. Mode of leaf arrangement

1.2 Organization of a Plant Cell

The geometric shape of angiosperm plant cells is determined by their rigid cell wall. A large part of the cell's interior is occupied by a vacuole. Additionally, the cell contains specialized organelles called chloroplasts.

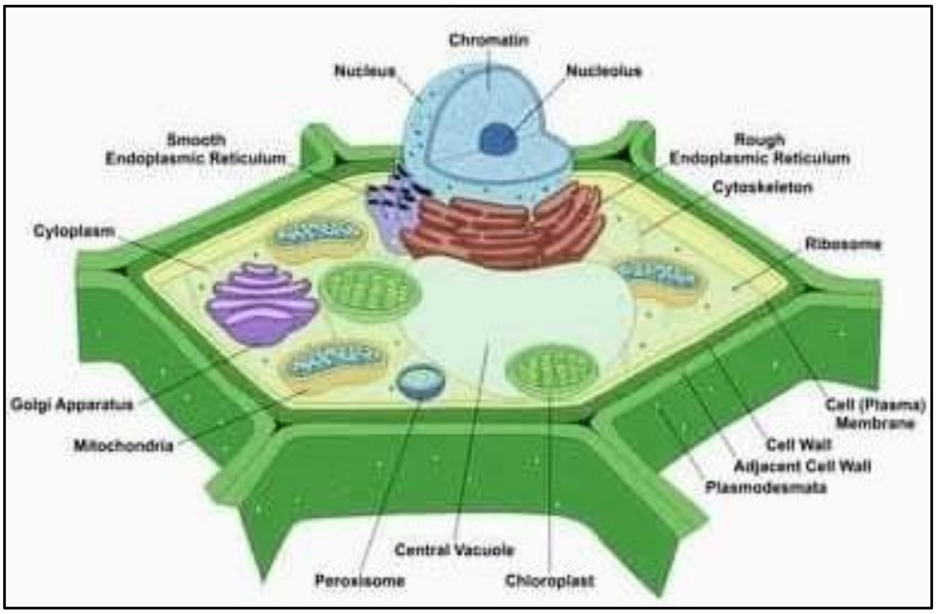

Figure.16. Plant cell : Parts and structure with fonctions

1.2.1. Organelles

Organelles are specialized structures within cells, each surrounded by a membrane and performing specific functions.

- **Nucleus :** This is a more or less spherical structure enclosed by the nuclear envelope, which contains almost all of the cell's DNA. It is the most prominent organelle visible under the microscope. The nuclear envelope consists of two membranes : an outer membrane in contact with the cytoplasm and an inner membrane in contact with the nucleoplasm. The space between these two membranes is called the perinuclear space. Nuclear pores are openings in the nuclear envelope that allow for the exchange of materials between the nucleus and the cytoplasm.
- **Chromatin:** Composed of DNA and proteins, chromatin is highly stainable with basic dyes. It appears as a diffuse network during interphase and condenses into chromosomes at the beginning of cell division.
- **Nucleolus:** A dense, mesh-like structure within the nucleus, the nucleolus is involved in the synthesis of ribosomal RNA and the assembly of ribosomes.
- **Endoplasmic Reticulum (ER):** This is a membrane-bound system of flattened sacs that are interconnected and may be studded with ribosomes. The ER comes in two forms:
    - **Rough Endoplasmic Reticulum (RER) :** Characterized by the presence of ribosomes on its surface, the RER is involved in protein synthesis and is highly developed in some cells, where it is known as ergastoplasm.

  - **Smooth Endoplasmic Reticulum (SER):** Lacking ribosomes, the SER is involved in lipid production, detoxification of harmful substances, and calcium storage.
- **Golgi Apparatus:** Composed of a stack of flattened sacs called cisternae, the Golgi apparatus receives protein vesicles from the RER. It modifies these proteins and packages them for secretion or delivery to other parts of the cell. It also contributes to protein processing and waste elimination.
- **Lysosomes :** These membrane-bound organelles contain enzymes essential for intracellular digestion and the breakdown of waste materials.
- **Peroxisomes:** Spherical or oval organelles that detoxify the cell by degrading certain molecules, such as fatty acids and alcohol, through processes like β-oxidation.
- **Cytoskeleton:** Composed of small actin filaments, the cytoskeleton provides structural support, helps organize organelles, and facilitates cellular movement and organization.
- **Centrosome:** Located near the nucleus, the centrosome consists of two centrioles oriented at right angles to each other. It is the primary site for microtubule organization and plays a crucial role in cell division, with each centrosome moving to opposite poles of the cell during mitosis.
- **Mitochondrion:** This rod-shaped organelle (0.5 to 1 µm) is surrounded by two membranes: a smooth outer membrane and a folded inner membrane. The intermembrane space has a chemical composition similar to that of the cytoplasm. Mitochondria contain their own DNA and vary in number among different cell types. Their main role is ATP synthesis.

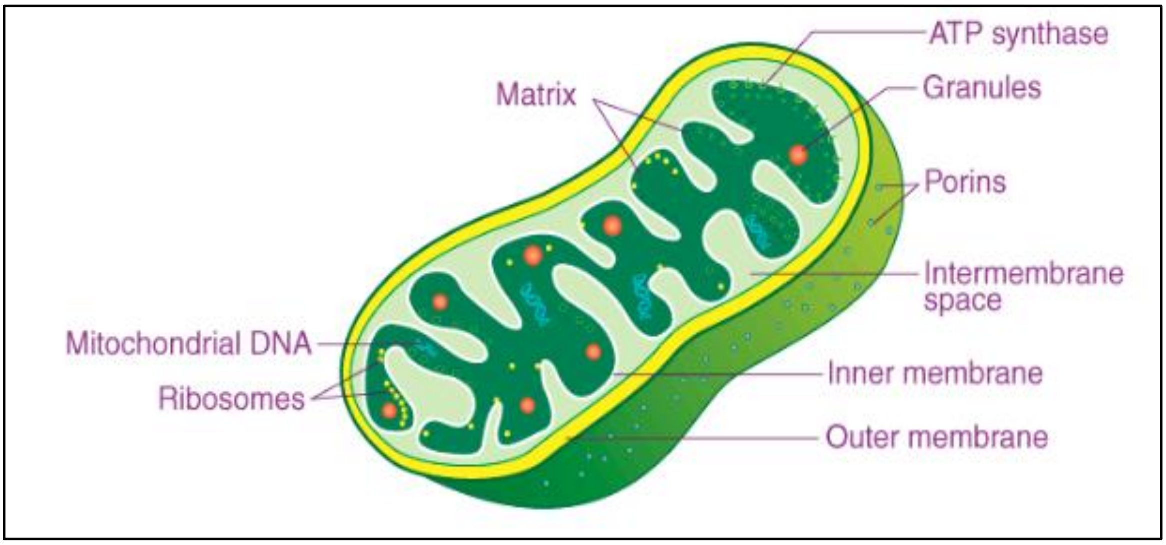

Figure .17. Mitochondria

- **Inclusions :** These are microscopic particles within the cell that contain storage substances or pigments. Inclusions do not play an active role in cellular functions.
- **The Cell Wall :** Plant cells are encased by two types of envelopes:
- **Pectocellulose Wall :** This thick and solid wall is primarily composed of cellulose, which is a product of secondary metabolism. Its main function is to provide structural support and to establish physical connections with neighboring cells.
- **Cell Membrane :** Located inside the cell wall, the cell membrane surrounds the cell's organelles and regulates the movement of substances into and out of the cell.

The pectocellulose wall consists of different layers that develop from the outside inward:

- **Middle Lamella :** The outermost layer, composed of pectic substances, serves as an intracellular cement, ensuring cohesion between adjacent cells.
- **Primary Wall :** Positioned between the middle lamella and the secondary wall, the primary wall is made of pectocellulose and can expand, facilitating cell growth and elongation.
- **Secondary Wall :** Formed during cell division, the secondary wall is located between the cytoplasmic membrane and the primary wall. It is composed of cellulose and hemicellulose and is rich in phenolic compounds.

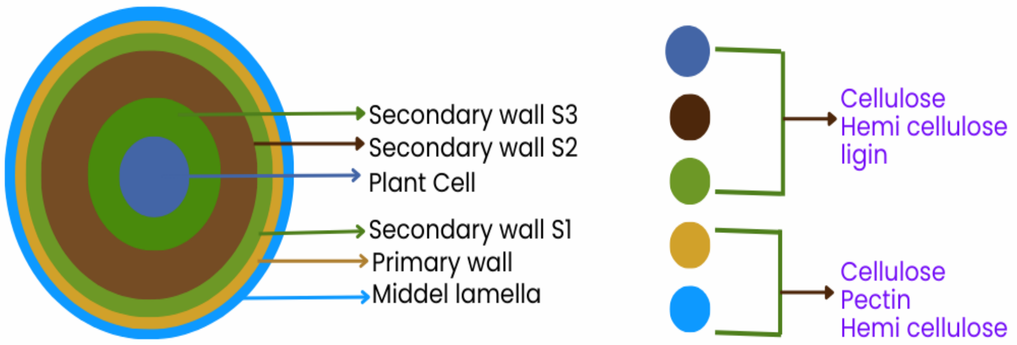

Figure.18. Plant cell walls

- **The Cell Membrane** : Plant cells possess two essential membranes :
- **Plasmalemma:** This thin membrane separates the intracellular environment from the extracellular environment and is formed by a lipid bilayer.
- **Tonoplast:** This membrane surrounds the vacuole and separates it from the cytoplasm, allowing selective permeability to substances stored in the vacuole.
- **Plastids** : Plastids are organelles found in the cytoplasm of eukaryotic plant cells. They contain their own DNA and are enclosed by a double membrane, with an inner and an outer membrane. Several types of plastids can be distinguished:

- **Proplastids:** Undifferentiated plastids that can develop into other types of plastids.
- **Etioplasts:** Plastids found in plants that are not exposed to light. They can develop into chloroplasts when exposed to light.
- **Chloroplasts:** A type of plastid containing pigments such as carotene and chlorophyll. Chlorophyll absorbs solar energy and converts it into chemical energy during photosynthesis. This process is responsible for the green color of plants and supports plant growth, which in turn provides energy for animals that consume plants.

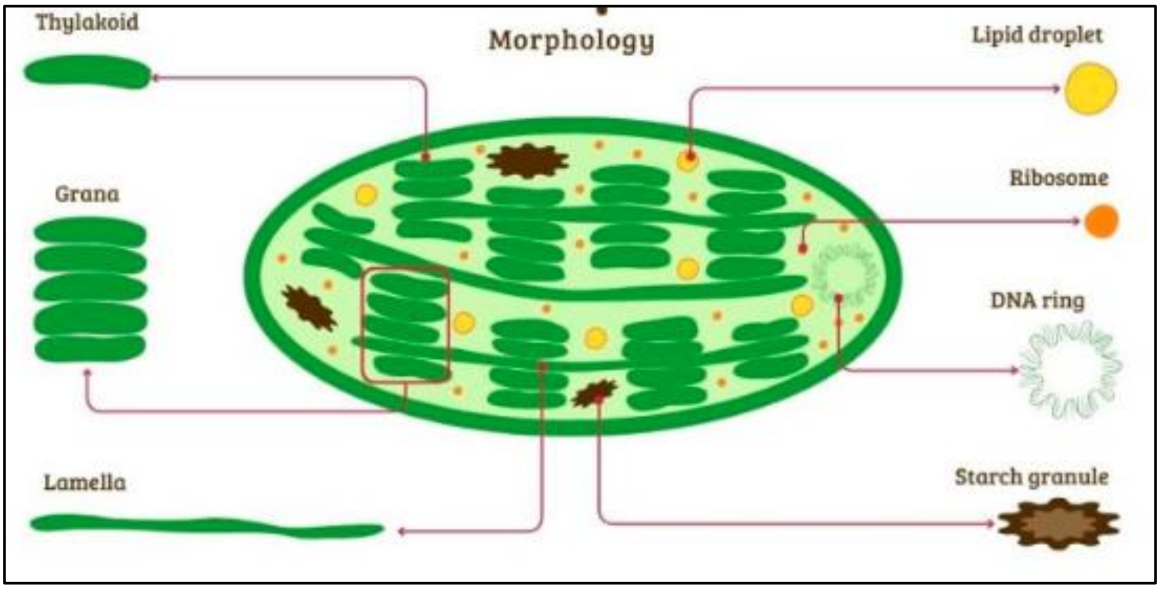

Figure .19. Chloroplasts

- **Chloroplasts** are plastids that contain pigments, including carotene. This pigment is responsible for the yellow, red, or orange hues seen in flowers, ripe fruits, and autumn leaves.
- **Chromoplasts** are generally found in plant cells exposed to light and can contain carotene. However, some cells that are not exposed to light, such as those in carrots growing underground, can also contain carotene.
- **Leucoplasts** are pigment-free plastids typically found in roots and tissues that do not photosynthesize. They specialize in the storage of different substances and are categorized based on their function:
    - **Amyloplasts**: Store starch.
    - **Oleoplasts**: Store lipids.
    - **Proteinoplasts**: Store proteins.

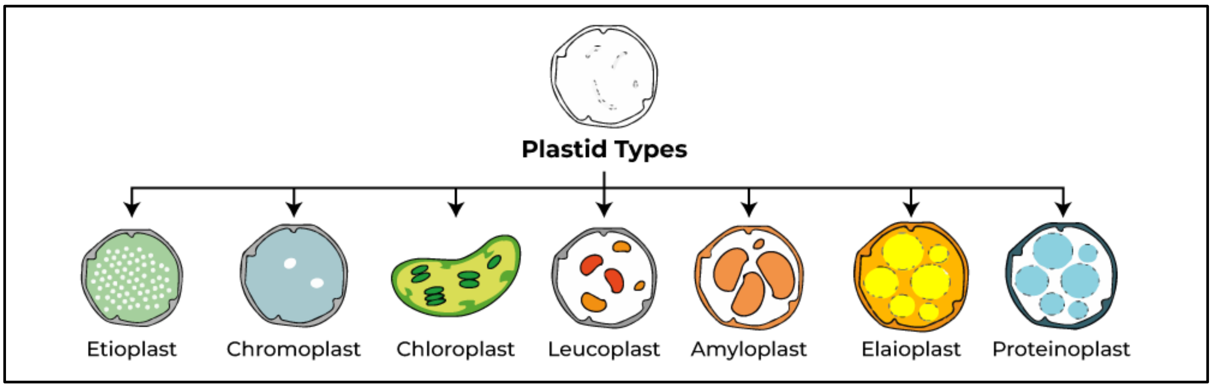

Figure .20. Different types of plastids

- **The vacuole** is a vital organelle found primarily in plant cells, characterized by its membrane, known as the tonoplast. It is filled with a solution of water, inorganic ions, and various organic molecules, playing a crucial role in maintaining cell turgor pressure and storing substances. In some plant cells, the vacuole can occupy up to 90% of the cell's volume, highlighting its importance in cellular structure and function. The vacuole interacts closely with the cytoplasm, facilitating the exchange of materials and contributing to cellular metabolism.

  The fluid inside the vacuole is referred to as vacuolar juice, which contains a mixture of solutes that can include sugars, acids, and other metabolites. The term "vacuolar apparatus"encompasses the entire structure and function of the vacuole within the cell.
- **Cytosomes** are spherical organelles within the cell, characterized by their simple membrane structure. They are known to contain various enzymes that play essential roles in metabolic processes. These enzymes facilitate biochemical reactions, contributing to the overall function and health of the cell.
- **Lysosomes** are specialized cytosomes that contain lytic enzymes capable of breaking down a wide range of macromolecules, including polysaccharides, proteins, and nucleic acids. These enzymes are crucial for cellular digestion and waste processing, allowing the cell to recycle components and maintain homeostasis. Lysosomes play a key role in autophagy, the process by which cells degrade and recycle their own components, as well as in the immune response by breaking down pathogens.

Chapter 2: Water nutrition

(Mechanism of water absorption and transit

Chapter 2: Water nutrition

(Mechanism of water absorption and transit

Introduction

Water is the most physiologically active and significant substance in plants, which is why water availability greatly influences plant distribution across the globe. Vegetation is abundant in well-watered areas but nearly absent in arid regions such as deserts. Like humans, plants require water to survive. Water is crucial for sap production, contributing to nutrient transport throughout the plant, and it also plays a key role in regulatory processes such as transpiration.

2.1. Water in the Plant :Water plays a crucial role in plant life on two levels:

a. **Cellular Level:** Water is the medium in which all metabolic reactions occur and where ions and metabolites diffuse.

b. **Organismal Level:** Water circulates in the plant's conductive vessels, creating raw and elaborated sap by dissolving various materials. It is also responsible for maintaining cell turgidity, which supports the upright growth of non-woody plants.

2.2. The Different States of Water in Plants

a. **Bound Water:** This water is tightly associated with cell structures and cannot be easily removed. It plays a critical role in various physiological processes.

b. **Open Water:** This is water that is easily accessible for general imbibition, circulating freely or remaining stagnant in the vacuoles.

c. **Water of Constitution:** This water stabilizes the tertiary structure of certain protein macromolecules. It cannot be removed without causing denaturation of these proteins. Drying processes typically do not remove bound water and water of constitution, which together represent about 3 to 5% of a material's total water content.

2.3. Water in the Soil

The difference between the total quantity of water in the soil and its availability is crucial. Water movement in the soil is influenced by various forces:

- **Osmotic Forces:** Soil ions attract and hold water.
- **Capillary Forces:** Surface tensions between water and soil particles cause capillary action.
- **Colloidal Forces:** Colloidal substances, which swell in the presence of water, become more significant in clayey soils. Colloids are large organic or mineral molecules that form a colloidal suspension rather than a true solution when placed in water.

Different types of soil water are classified according to these retention forces:

- **Gravity Water:** This is free water that moves through the soil due to gravity and is retained to varying extents by osmotic and imbibition forces.
- **Capillary Water:** This free water is held in the soil by capillary forces.
- **Hygroscopic Water:** This water is tightly bound to soil particles and is not available for plant use, as it is an integral part of the soil's composition.

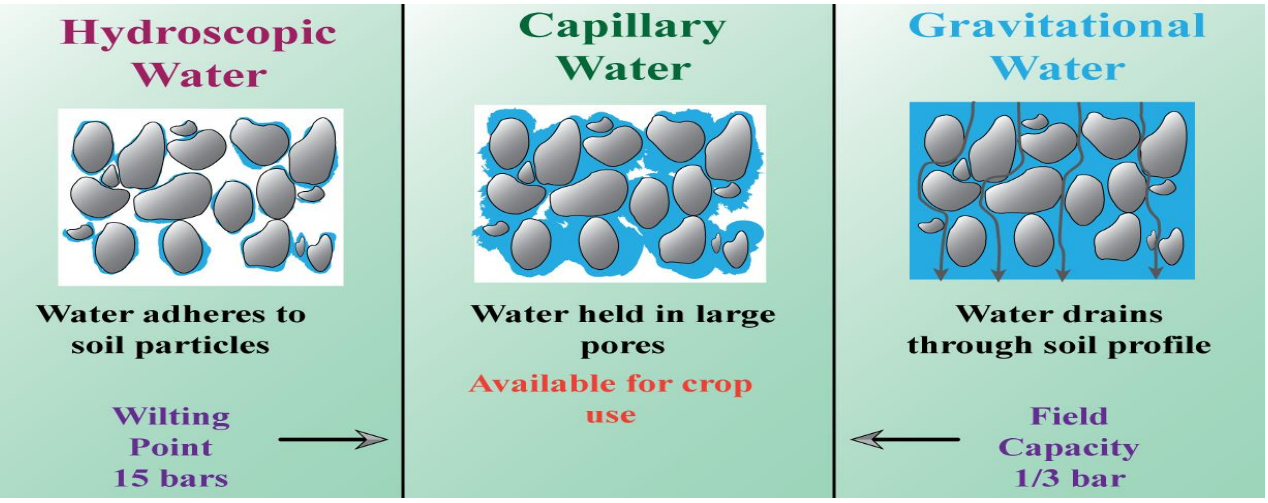

Figure.21. Water states in the soil

2.4. Water Potential

Water potential is used to evaluate the direction of water exchanges between:

- Various plant components (organs, cells, etc.).
- Soil and vegetation.
- Plants and their environment.

Water moves from areas of higher water potential to areas of lower water potential.

The water potential of a soil represents the energy required to extract 1 gram of water. It is always a negative value, with the magnitude of the negativity increasing as the bond between water and soil becomes stronger. Water moves from regions of higher (less negative) potential to regions of lower (more negative) potential, indicating movement from more hydrated to less hydrated areas.

As the soil dries out, its water potential decreases and becomes more negative.

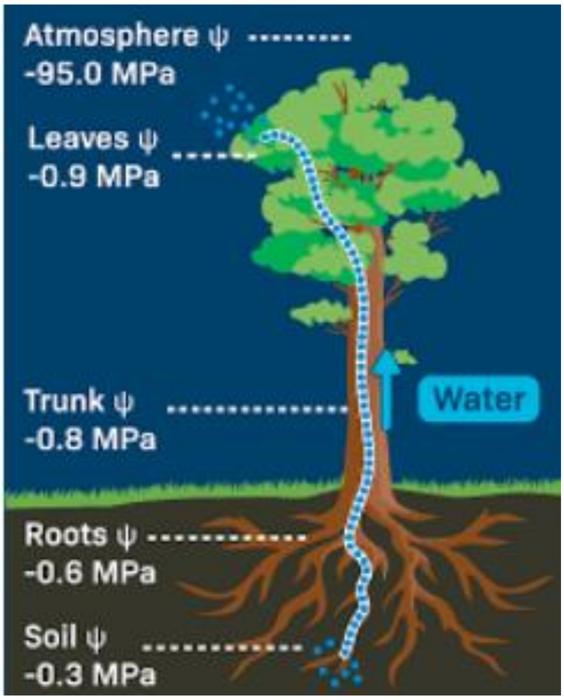

Figure .22. Plant water potential

The energy required to extract water from a solution (such as soil solution, cytoplasm, or vacuole) is referred to as water potential. Any substance dissolved in an aqueous solution (such as ions or molecules) exerts an attractive force on water molecules. The concentration of the solute increases this attractive force, which reduces the ability of water molecules to leave the solution. Water potential, denoted as Ψ, represents the potential for water to move out of a specific compartment. As the water potential becomes less negative (increases), water tends to leave the compartment. Conversely, water moves into compartments with a lower (more negative) water potential.

Water molecules continuously move from regions of high water potential (less negative) to regions of low water potential (more negative). A hypertonic solution has a low water potential due to a high concentration of dissolved solutes, which attracts water from other solutions by osmosis. A hypotonic solution has a low concentration of dissolved solutes, resulting in a high water potential. Isotonic solutions have equivalent concentrations of dissolved substances, resulting in no net movement of water.

The water potential of a plant cell consists of two components :

- **Osmotic Potential ($\Psi\pi$):** Also known as solute potential, it reflects the potential of water to move due to the presence of solutes.
- **Pressure Potential (Ψp):** Also known as turgor pressure, it is the physical pressure exerted by the cell wall against the internal pressure of the cell.

$$\mathbf{\Psi = \Psi\pi\ (\Psi s) + \Psi p}$$

- **Ψs (Osmotic Potential):** This is the potential due to solutes. In pure water (distilled water), the osmotic potential is equal to 0, and it is always negative in plant cells. It reflects the presence of dissolved substances. As the number of solute particles increases, the osmotic potential (Ψs) becomes more negative. Therefore, an increase in solutes leads to a decrease in Ψw (water potential).
- **Ψp (Pressure Potential):** This represents the physical pressure exerted by water on the surrounding environment, also known as turgor pressure. It is always positive in plant cells.

Here is the corrected and formatted version of your examples:

Water potential predicts the movement of water in and out of cells.

Example 1:

- External environment: Ψw = 0 MPa
- Inside the cell: Ψp = 0.5 MPa and Ψs = -1.6 MPa

Does water enter the cell?

Answer:

1. Calculate the cell's water potential (Ψw): Ψw=Ψp+ΨsΨw = Ψp + ΨsΨw=Ψp+Ψs Ψw=0.5−1.6Ψw = 0.5 - 1.6Ψw=0.5−1.6 Ψw=−1.1 MPaΨw = -1.1 \text{ MPa}Ψw=−1.1 MPa
2. Compare the water potentials:
    - Cell's water potential (Ψw) = -1.1 MPa
    - External environment's water potential (Ψw) = 0 MPa

Since the cell's water potential (-1.1 MPa) is lower than that of the external environment (0 MPa), water will move into the cell from the external environment.

Example 2:

- External environment: Ψw = -2.5 MPa
- Inside the cell: Ψp = 0 MPa and Ψs = -2 MPa

Does water enter the cell?

Answer:

1. Calculate the cell's water potential (Ψw): Ψw=Ψp+ΨsΨw = Ψp + ΨsΨw=Ψp+Ψs Ψw=0−2Ψw = 0 - 2Ψw=0−2 Ψw=−2 MPaΨw = -2 \text{ MPa}Ψw=−2 MPa
2. Compare the water potentials:
    - Cell's water potential (Ψw) = -2 MPa
    - External environment's water potential (Ψw) = -2.5 MPa

Since the cell's water potential (-2 MPa) is higher than that of the external environment (-2.5 MPa), water will move out of the cell into the external environment.

2.5. The Water Content of Plants

A plant's water content results from a balance between water intake (primarily from the soil) and water loss through transpiration. The connection between a plant and its environment is delicate; even though various regulatory mechanisms are in place, the plant is heavily dependent on the water it receives. Any deficit in this water balance can lead to wilting, withering, and eventually the death of the plant.

To measure plant water content, plant material is typically dried and compared to its fresh weight. The process involves drying the material in a high-temperature oven (70-110°C) under vacuum until it reaches a constant weight. Alternatively, water can be removed using successive baths of xylene or toluene, although these solvents also dissolve other components, such as lipids. Another commonly used method is cryodesiccation or freeze-drying.

Plant cells use the large vacuole as a reservoir for water. Water circulates throughout the plant via sap-conducting vessels: the xylem (which carries raw sap) and the phloem (which carries elaborated sap).

Here's the corrected and clarified version of the text:

Water Content Calculation:

The water content of a plant is calculated using the formula:

θ=MF−MSMF×100\theta = \frac{MF - MS}{MF} \times 100θ=MFMF−MS×100

where:

- θ\thetaθ is the water content in percent,
- MFMFMF is the fresh matter,
- MSMSMS is the dry matter.

The water deficit is calculated using the formula:

Dθ=θm−θθmD\theta = \frac{\theta_m - \theta}{\theta_m}Dθ=θmθm−θ

where:

- θm\theta_mθm is the maximum water content,
- θ\thetaθ is the actual water content.

2.6. Water Penetration into the Plant

2.6.1. Water Uptake by Roots

Root hairs are primarily responsible for water absorption into the plant. These specialized structures are large cells, typically ranging from 0.7 to 1 mm in length and 1.2 to 1.5 μm in diameter, forming visible hair-like projections just behind the root apex. They are extremely numerous, with densities of 200 to 500 per square centimeter, and can reach up to 2000 per square centimeter in grasses. In some plants, such as rye, there may be over 14 billion root hairs per plant.

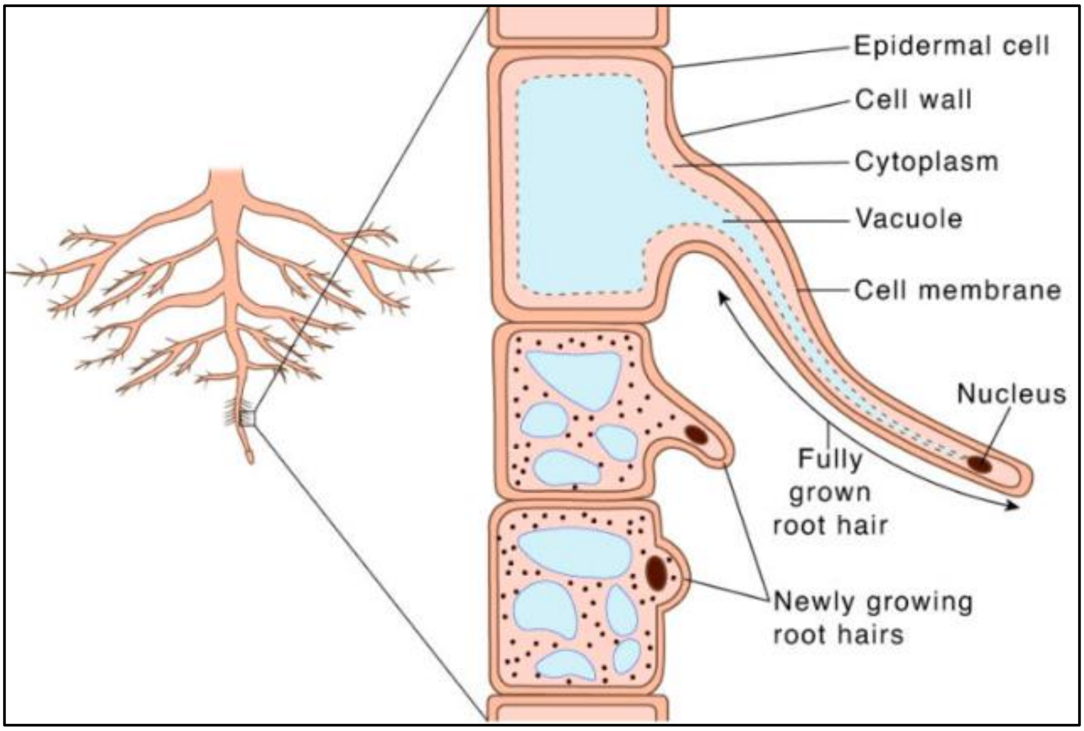

Figure.23. Diagram of an absorbent root hair

2.6.1.1. Absorbent hairs provide a large contact surface between the soil and the plant, increasing the surface area of the roots by 2 to 10 times, potentially reaching tens or even hundreds of square meters. These hairs are temporary structures, lasting from a few days to a few weeks, and are continuously renewed as the root grows. They are sensitive to environmental conditions such as soil acidity and lack of oxygen, which can lead to their degradation.

Although absorbent hairs are numerous, water absorption is not exclusive to them. These hairs do not have specific absorption mechanisms but possess morphological characteristics that enhance water exchange. Water absorption is significantly lower in the suberized (or corky) parts of the roots but still occurs in cracks and lenticels, which can be crucial for large trees.

2.6.2. Factors Controlling Plant Water Uptake

Water absorption is closely linked to the plant's physiological activities. Transpiration creates a negative pressure that is transmitted from the stem to the cells through the cohesive forces of water. This pressure, or "pull," has a dual role:

- It directly influences water uptake by the roots.
- It reduces the size of the absorbent hairs, thus lowering the counter-pressure exerted by turgor.

Root activity and water uptake are also influenced by various factors, including:

- **Climatic Factors :**
- **Climatic Factors:** Absorption is influenced by air temperature and humidity, which affect the amount of water lost through transpiration. Soil temperature also plays a crucial role; a drop in temperature of less than 5 to 10°C can reduce absorption.
- **Edaphic Factors:** Root asphyxia can occur in soils that are too heavy or too wet, which hampers absorption. Therefore, the water content of the soil, particularly the free water available to vegetation, is crucial.

2.6-3. Methods for Measuring Water Uptake by Roots

It is generally accepted that the quantity of water absorbed is equivalent to the quantity of water lost through transpiration. The quantities of water transformed or produced by metabolism are negligible compared to the massive amounts of water circulating through plant organisms. The quantity of water collected in the soil by a plant can be measured in various ways:

- By simple weighing,
- Using a potometer.

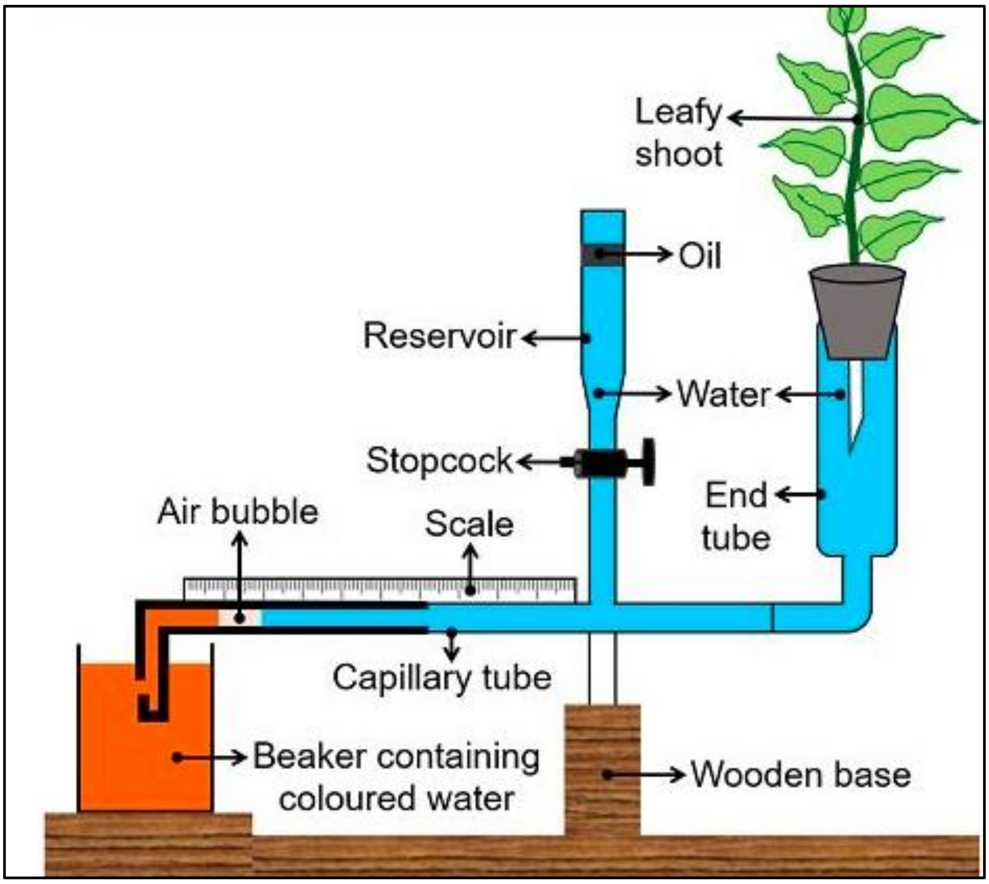

Figure.24. Vescque potometer model

Evaluating the flow of water away from the base of a cut stem .

Figure .25. Guttation in plants

However, these methods have limitations. They either involve the simultaneous action of both the aerial and root systems, which results in water loss due to both absorption and transpiration—two interrelated physiological processes—or the complete removal of the aerial vegetative system, which eliminates the control of transpiration over absorption. Despite these imperfections, these methods provide an estimate of the water absorbed by plants each day.

On average, a plant absorbs an amount of water roughly equivalent to its own volume each day:

- A temperate forest tree absorbs about 500 liters per day, which translates to approximately 30 tonnes of water per hectare (t/ha) of forest.
- A vine plant absorbs about 1 liter per day.

2.7. Water Absorption, Transport, and Emission

The plant's roots absorb water from the soil to support its biosynthesis and transpiration processes. Transpiration is the process by which water is transported from the soil through the plant to the leaves, where it evaporates. This process accounts for the vast majority of the water absorbed by the plant. The movement of water in the soil and within the plant is passive, following a spontaneous flow from areas of high water availability (moist soil with high water potential) to areas of lower water availability (drier, lower water potential in the leaves and atmosphere).

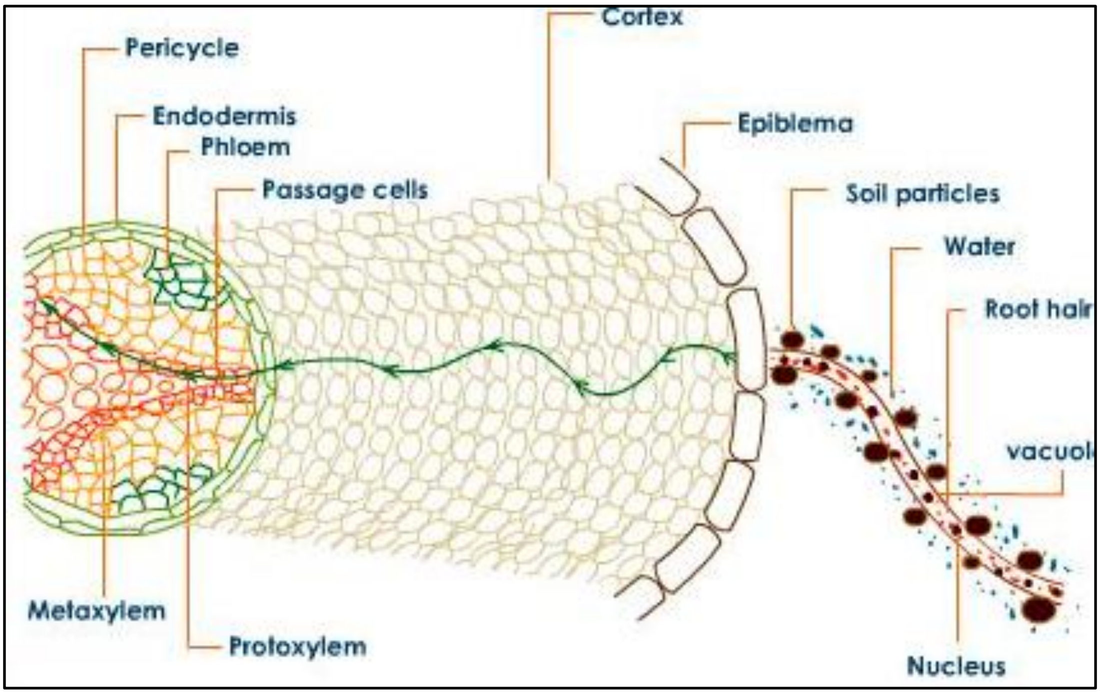

Figure.26 : Water flow from the absorbent hair to the root endodermis.

2.7.1. Water Absorption

In one day, a plant absorbs a volume of water approximately equal to its mass. Higher plants absorb water through their absorbent hairs, which are attached to the roots. The physical laws of diffusion explain why water is consistently absorbed by a cell wall or membrane. Osmosis, a form of passive transport, occurs from a hypotonic medium (less concentrated) to a hypertonic medium (more concentrated). Osmotic pressure is the force exerted due to the concentration difference between two solutions separated by a semi-permeable membrane. As a result, a cell immersed in a hypertonic solution (where the external environment is more concentrated than the internal environment) will lose water and experience plasmolysis. Conversely, if the extracellular environment is more hypotonic than the intracellular environment, water will enter the cell, causing the vacuole to swell and the cell to become turgid.

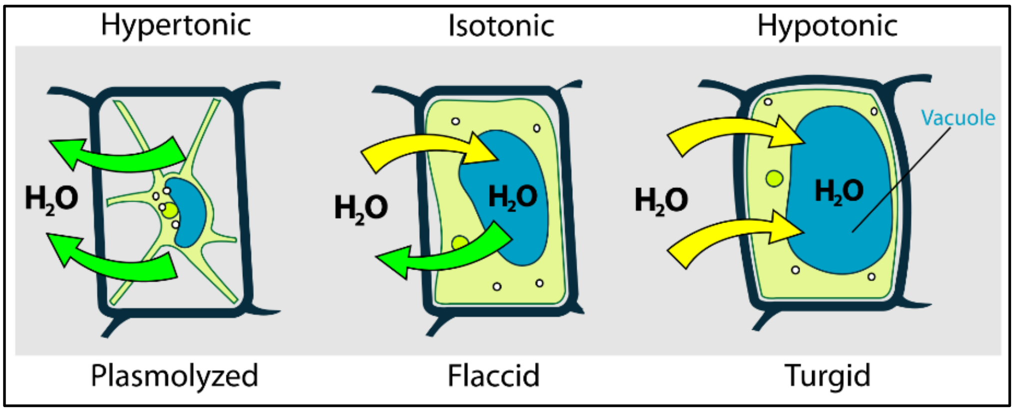

Figure.27: Water in the cell

2.7.2. Water Transport

Absorbent hairs transport water and mineral salts to the endodermis. This progression occurs according to the principles of osmosis. Water movement can take place apoplastically (through the cell walls) and symplastically (through the vacuoles and cytoplasm). In the endodermis, where the cell layers are thickened by Casparian bands, water must pass symplastically.

Once water reaches the conductive elements of the xylem, it is transported to the leaves via the root and stem, where the majority of the water is lost to the atmosphere through transpiration. Thus, the soil-plant-atmosphere continuum facilitates the movement of water.

Water can follow at least one of the following three routes through the root:

- **Apoplastic Route**: Water moves through the cell walls and intercellular spaces, bypassing the cell membranes.
- **Symplastic Route**: Water moves from one protoplast to another via plasmodesmata. It circulates from cell to cell, passing through the vacuoles. Note that the protoplast of a plant cell refers to the living part of the cell, excluding the cell wall.

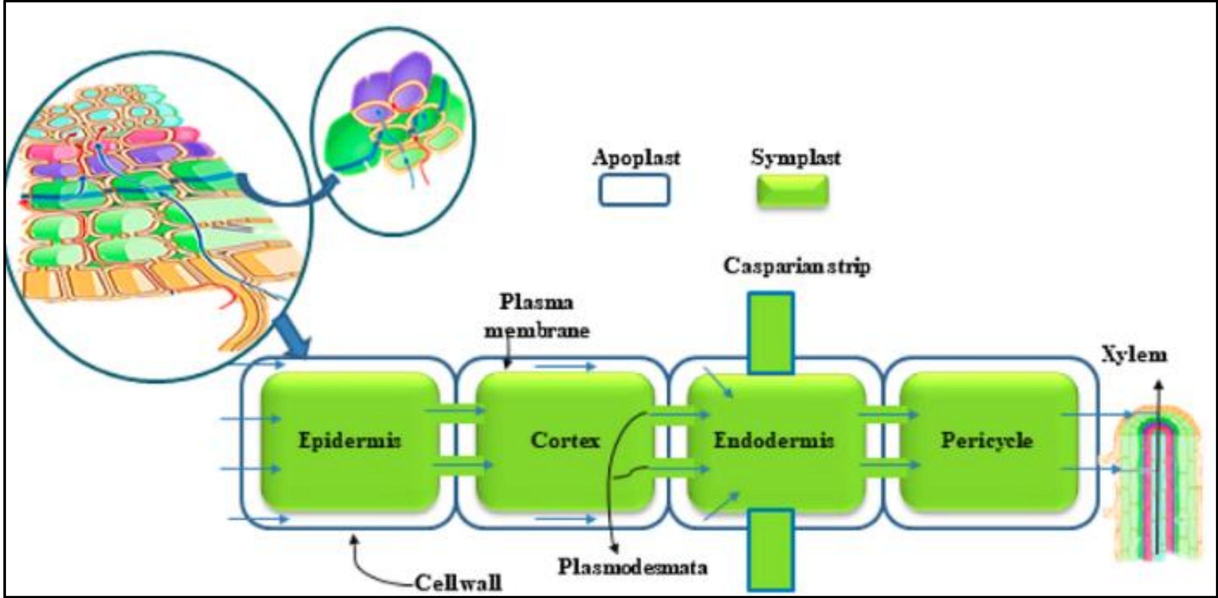

Figure.28. Mechanism of water transport by apoplastic and symplastic pathways. Conceived from Burridge et al. (2022), Li et al. (2022), Rafie et al. (2022)

Chapter 3: Perspiration and water balance

Chapter 3: Perspiration and water balance

Introduction

Plant transpiration plays a crucial role in maintaining a plant's water balance. This continuous process is defined as the emission of water in the form of vapor. Meanwhile, the roots absorb the corresponding amount of water from the soil.

3.1 How It Works

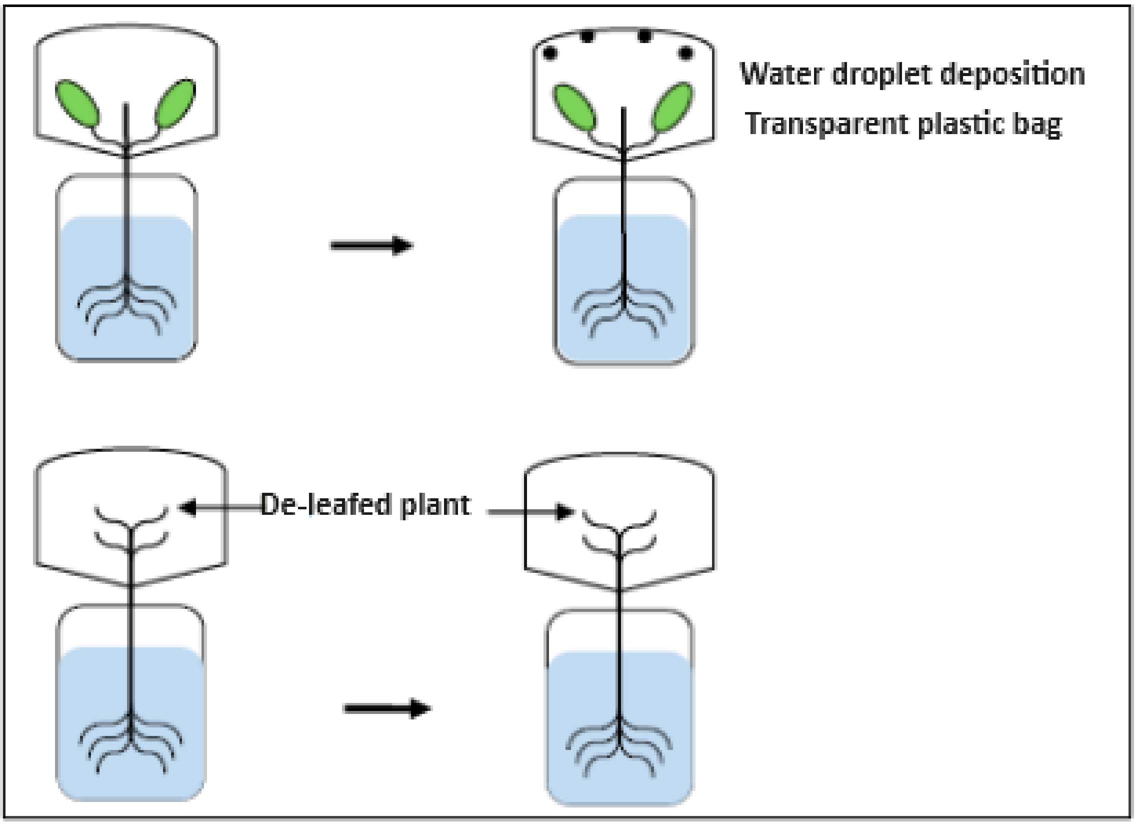

Figure .29. Evidence of perspiration

Transpiration refers to the emission of water vapor by plants into air that is not saturated with moisture. It is a fundamental mechanism for maintaining plant water balance, as it facilitates the circulation of water within the plant and the exchange of water between the soil, plant, and air. Transpiration indirectly contributes to water uptake by the plant, serving as the driving force behind sap flow.

Transpiration occurs in two distinct stages: cuticular transpiration through the cuticle, and stomatal transpiration through the stomata. A tree can transpire up to 220 liters per hour. The transpiration rate of plants is roughly equivalent to that of a body of water of the same size, which would lose water at a rate of 1/6.

3.2. Location and measurement

3.2.1. Cobalt chloride experiment

A plant is placed in a pot, and a leaf is positioned on either side of a rectangle of filter paper saturated with dehydrated cobalt chloride. Dehydrated cobalt chloride is blue, while the hydrated form turns pink. After 30 minutes, the cobalt chloride-soaked paper shows small pink spots, which correspond to ruptures in the leaf epidermis, specifically at the stomata. This indicates that excess water is being released through the stomata. In addition to stomatal transpiration, the cuticle and lenticels also contribute to transpiration.

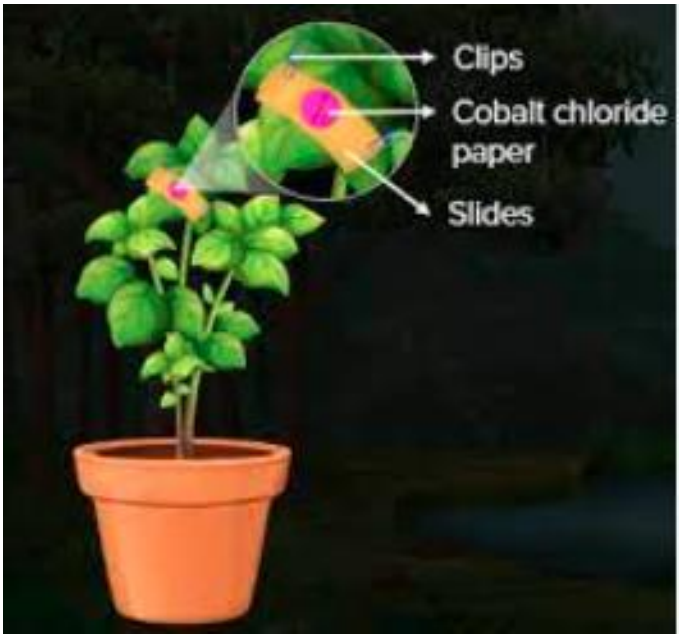

Figure .30. Cobalt chloride experiment

3.2.2 Stomata

The use of a stomata promotes gas exchange between the plant and the environment (oxygen O2, carbon dioxide CO2, water vapor, etc.) and regulation of osmotic pressure.

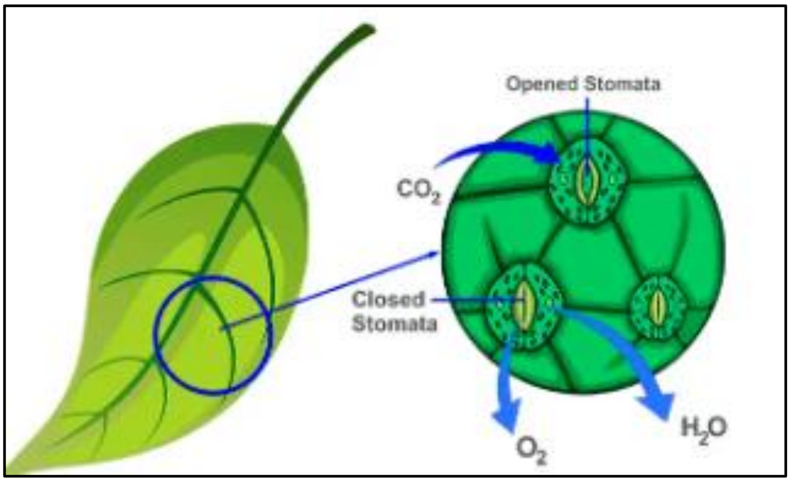

Figure .31. Stomata diagram

3.2.3. Structure

The stomatal structure consists of two kidney-shaped guard cells that enclose a stomatal opening or ostiole. Each guard cell contains a large vacuole, a small parietal nucleus, mitochondria, and chloroplasts. Above the guard cells is the substomatal chamber, a cavity that is situated just beneath them. The guard cells have a thick, cutinized inner wall, while the outer wall is thin and composed solely of cellulose.

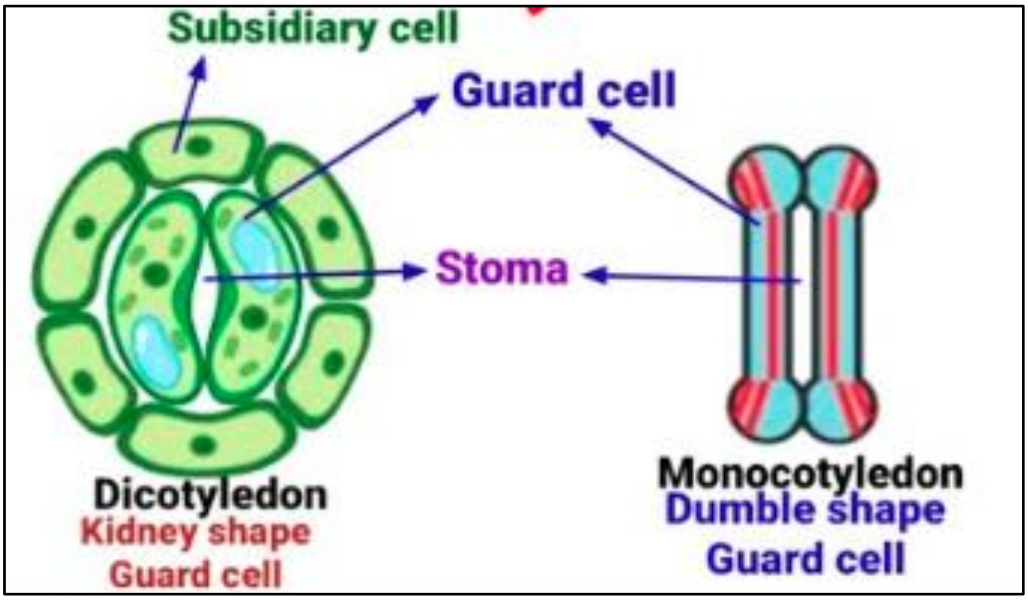

Figure .32. Stomatal structure

There are stomata known as "aquatic stomata" that emit water in liquid form, a phenomenon known as guttation. These are found on the edges of leaves and on nectar-secreting structures. Generally, they are very rare and lack a substomatal chamber. The surface tissue is specialized for this function, the guard cells do not contain chloroplasts, and the ostiole remains intact.

3.2.4. Mechanisms of Stomatal Opening

The opening and closing of stomata regulate stomatal transpiration, which fluctuates with changes in osmotic pressure within the guard cells. Stomata consist of guard cells that open or close in response to osmotic forces related to fluctuations in potassium concentration inside the cells. Increasing potassium levels creates a hypertonic environment, causing the guard cells to become turgid and thus opening the stomata. The walls of the guard cells, which are often accompanied by epidermal companion cells that lack chloroplasts, reinforce the inner side of the ostiole. These companion cells are in close contact with the guard cells on their external surfaces, facilitating increased intercellular exchanges.

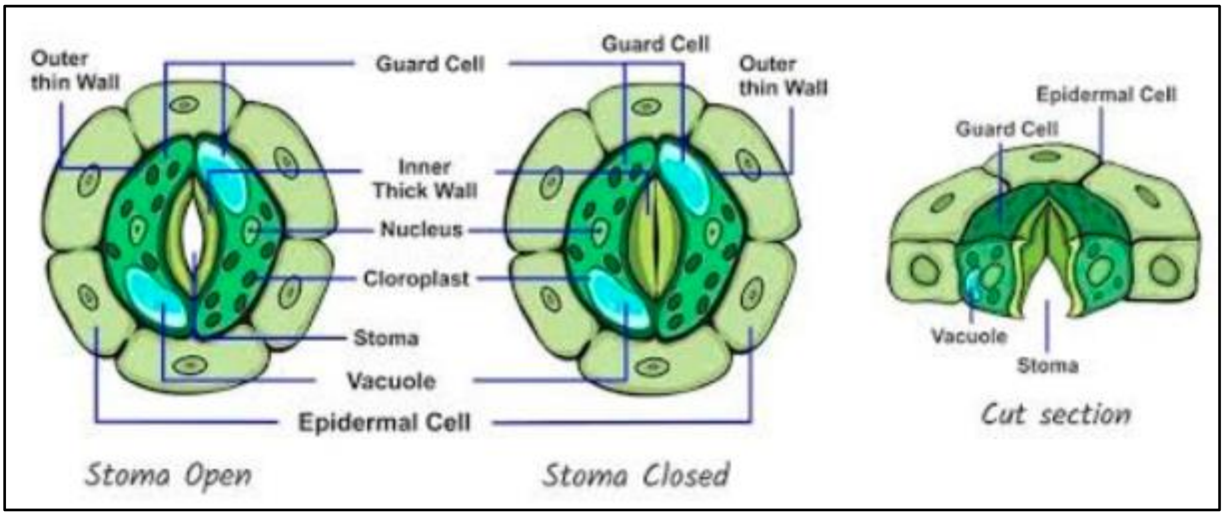

Figure .33. Stomata opening and closing mechanisms

3.4 Stomatal Regulation

Stomatal regulation is a plant response aimed at improving photosynthesis efficiency or reducing water loss.

- The opening of the stomatal pore is influenced by the CO_2 concentration in the leaf's internal atmosphere: low CO_2 levels lead to stomatal opening, while high CO_2 levels lead to closure.
- Light triggers stomatal opening, likely through photosynthesis by mesophyll cells, which absorb CO_2, reducing its concentration and causing the stomata to open. The exact mechanism is still unclear, but light may promote the active entry of K^+ into guard cells.
- Water deficiency in leaf cells results in the production of abscisic acid, which causes the stomata to close.

3.5 Factors Influencing Transpiration

3.5.1 Internal Factors

These are anatomical or physiological adaptations that differ among species, enabling them to adjust their transpiration in response to climatic conditions:

- Xerophytic plants have low stomatal density, and CAM plants keep their stomata closed during the day.

	Number of stomata per mm^2 (leaf)	
	Top side	Bottom side
Dahlia	22	30
Begonia	0	40
lily	0	62
Tomato	12	130
Oats	25	23
Sunflower	175	325

In xerophytes, stomata are often located at the bottom of small depressions or are covered by a layer of trichomes, which provides protection. Tough, aerial organs (such as stems and leaves modified into spines) in sclerophytes are often supported by well-developed tissues, which restricts the movement of these organs. Mucilages in cacti and the high osmotic pressure in halophyte cells help retain water within the tissues.

3.5.2 External Influences

Key external factors include:

- **Soil Moisture:** A decrease in soil moisture reduces water absorption, which can lead to increased transpiration.
- **Air Movement:** Wind enhances transpiration by continuously renewing the air around the leaves. Natural or artificial windbreaks can reduce transpiration.
- **Humidity:** Relative humidity, which depends on air temperature, affects transpiration. In temperate regions, humidity typically averages around 60%. It can reach 100% in fog, while in deserts, it is below 10%. Plants increase transpiration when air humidity is insufficient.
- **Temperature:** The effect of temperature on transpiration is similar to that of air dryness: transpiration increases up to around 30°C, but beyond this temperature, it decreases due to stomatal closure.
- **Light:** Light causes stomatal opening. The energy used to evaporate the water is solar energy, which constitutes 50% of the solar energy reaching the leaf.

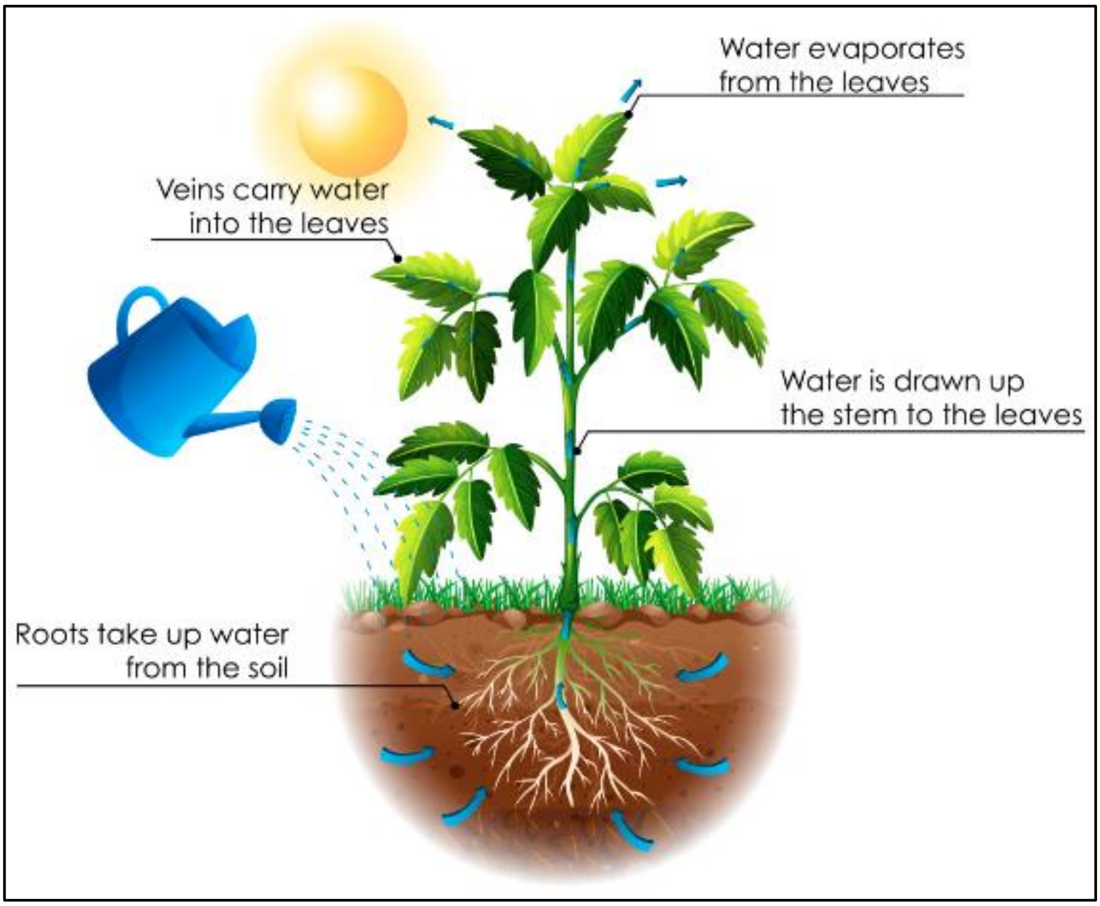

Figure.34. Factors influencing perspiration

3.6 Measurement of Transpiration

- Various methods can be used to measure water exchange:
  - The weight loss of an unwatered plant can be measured within 2 minutes after removal.
  - The amount of water emitted can also be measured by absorbing it with chemicals such as calcium chloride [$CaCl_2$], phosphorus pentoxide [P_2O_5], or sulfuric acid [H_2SO_4] as it is released.
  - A potometer measures water absorption; measuring the water emitted by a plant can also provide an estimate of the absorption, though this can only be a rough indication.

3.6.1. Transpiration Intensity (TI)

This refers to the amount of water lost (in grams) per unit leaf area (in dm^2) per hour. The transpiration rate in $g/m^2/h$ is approximately 11 $g/m^2/h$ for oats, 6 $g/m^2/h$ for oranges, and 2 $g/m^2/h$ for ivy. Transpiration intensity is regulated by the degree of stomatal opening, which is influenced by structural (morphological) and external factors. Plants can be classified as follows:

- Hygrophytes (wet habitats): ~10 g of water per dm^2 per hour.
- Mesophytes (dry and wet conditions): ~1 g.
- Xerophytes (dry habitats): ~0.1 g.

3.6.2. Transpiration Coefficient

The amount of water (in kg) required by a plant to produce 1 kg of plant biomass is known as the transpiration coefficient. For example, it takes 238 kg of water to produce 1 kg of corn silage and 850 kg of water to produce 1 kg of alfalfa.

3.6.3. Water Evaporation

Water loss from a plot includes both plant transpiration and direct evaporation from the soil. The amount of water emitted by plant transpiration in a given area is difficult to distinguish from the amount lost due to soil evaporation. Therefore, the combined effect of both processes, known as evapotranspiration, is considered. In practice, reducing soil evaporation (e.g., through cultivation) can be beneficial.

3.6.4. Water Balance

The amount of water in a plant’s tissues at any given time is the result of absorption and transpiration. During the day, transpiration typically exceeds absorption, while at night, absorption usually dominates. Maintaining a balance in the plant's water budget is crucial. Farmers need to adjust inputs and losses accordingly.

- If inputs exceed losses, it may be necessary to drain excess water to prevent soil asphyxiation.
- If inputs are less than losses, the farmer has two options:
    - Increase resources through irrigation.
    - Reduce losses, which can be achieved by:

- Reducing soil evaporation (e.g., through surface treatments or mulching).
- Reducing transpiration using methods such as:
- Installing windbreaks.
- Creating artificial mist to increase relative humidity (e.g., in cold storage rooms where humidity often reaches 80%).
- Using shading to reduce temperature and light, or employing cooling systems.
- Applying antitranspirants.
- Reducing the evaporation surface (e.g., through pruning or reducing the leaf area of cuttings).

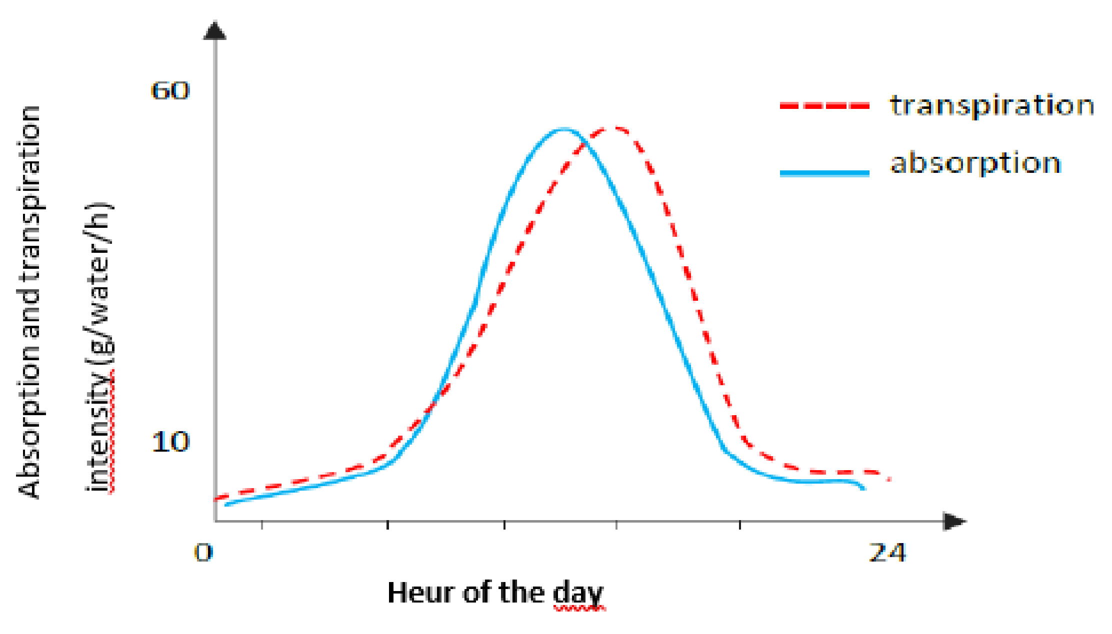

Figure .35. Absorption and transpiration

3.6.5. Role of plant transpiration:

- Guarantee water circulation within the plant
- Maintain water balance
- Transfer mineral salts to leaves
- Contribute to the movement of prepared sap.

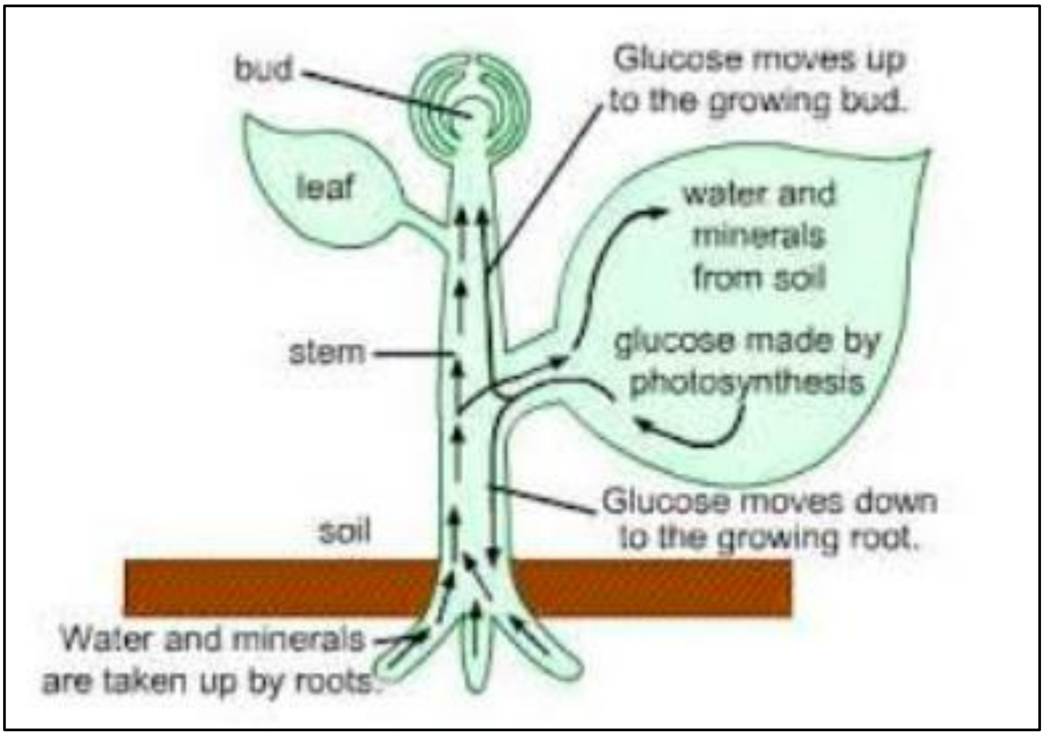

Figure .36. Role of plant transpiration

Chapter 4: Mineral nutrition
(macro and trace elements)

Chapitre 4 : Nutrition minérale (macro et oligo -elements)

Introduction

Les racines de la plante sont alimentées par des sels minéraux présents dans le sol sous forme d'ions. La présence de vastes surfaces racinaires et de systèmes d'absorption actifs explique que, même si les concentrations d'ions dans la solution du sol sont faibles, l'assimilation des nutriments minéraux par les plantes est un processus extrêmement efficace. De plus, des interactions entre des bactéries ou des champignons (mycorhizes) et les racines contribuent à l'assimilation de ces minéraux.

4.1. Détermination des besoins nutritifs des végétaux chlorophylliens

La compréhension des mécanismes moléculaires du transport ionique et des gènes impliqués dans la nutrition minérale a été connue de grandes avancées récemment. Les plantes chlorophylliennes extraient des substances minérales essentielles à leur existence dans leurs environnements (sol, eau et air).

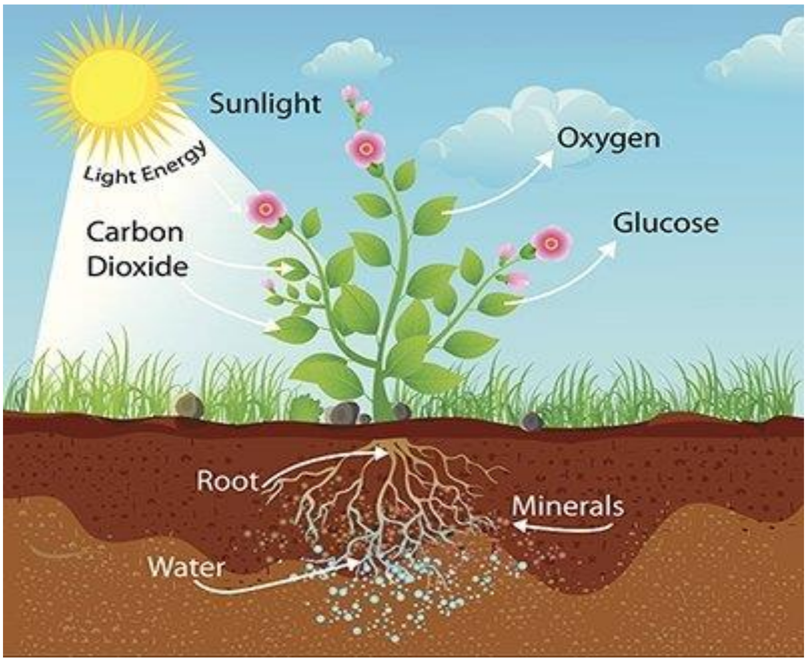

Figure .37. Besoins de la plante

4.1.1. Les éléments minéraux et la fertilité du sol (nature et importance).

- Un élément indispensable est un composé chimique nécessaire à une plante pendant son cycle de développement, impliquant le passage de l'état de graine à la production d'une nouvelle génération de graines. Afin qu'un élément soit considéré comme essentiel, il est nécessaire de remplir trois critères :

- Une plante donnée doit ne pas pouvoir réaliser son cycle sans l'élément minéral en question,
- Dans sa fonction, cet élément ne doit pas être remplacé par un autre élément minéral,
- L'élément doit être directement impliqué dans le minéral de la plante – par exemple, comme un constituant essentiel de la plante tel qu'une enzyme – ou il doit être nécessaire dans une étape métabolique différente, comme une réaction d'une enzyme. Les éléments essentiels d'une plante sont généralement classés en :
- -principales composantes macroélémentaires : azote (N), phosphore (P), potassium (K) ; et composantes secondaires : calcium (Ca), magnésium (Mg), soufre (S), sodium (Na). **L'azote** est l'un des éléments essentiels pour la croissance des végétaux, sa pénurie ayant un impact considérable sur la diminution de la croissance. C'est un composant des protéines, des acides aminés, de la chlorophylle et de l'ADN.
- **Le phosphore** joue un rôle essentiel dans la photosynthèse, le contrôle de l'énergie métabolique (ATP) et participe à la formation d'enzymes et de nombreuses molécules. Il favorise la progression et l'épanouissement des racines et des fruits.

  La pression osmotique, la régulation stomatique, l'économie de l'eau, ainsi que la résistance au stress hydrique, au gel et aux maladies sont des domaines où le potassium joue un rôle crucial.

  Le manganèse (Mn), le zinc (Zn), le chlore (Cl), le bore (B), le molybdène (Mo), le cobalt (Co). Ces éléments sont présents dans les enzymes et varient selon les espèces. Les crucifères contiennent du soufre, les algues du potassium, les graminées, les prêles et les fougères du silicium. Des différences existant en fonction des organes d'une plante. La plante contient plus de phosphore et moins de potassium que la graine. Le calcium est plus présent dans les parties âgées, tandis que le potassium, le phosphore et l'azote sont plus présents dans les parties jeunes.

4.1.2. L'origine des minéraux.

Selon la nature et le pH du sol, les ions sont présents en solution dans le sol. Ils se trouvent soit à l'état solide dans le complexe argilo-humique (dans des solutions colloïdales), soit dans le complexe anionique. Si un cation est fixé par la paroi, et si celui-ci est divalent, il accrochera l'anion au sol. En présence d'un grand nombre de complexes argilo-humiques, le sol sera riche. La plupart des ions sont métabolisés par la plante afin d'être exploités. Par exemple, on observe une diminution des sulfates au niveau des chloroplastes. Souvent, ces ions seront à des concentrations faibles. La plante contient également des ions à haute concentration.

Cette sélectivité s'observe chez une plante pour l'absorption des ions et pour le maintien de la concentration de ces ions.

Dans le complexe argilo-humique, les ions sont étroitement liés : la plante et le complexe ionique se concurrencent pour capter des ions, ce qui entraîne une consommation d'énergie par le végétal.

4.2. Modalités et mécanismes de l'absorption. Cette sélectivité s'observe chez une plante pour l'absorption des ions et pour le maintien de la concentration de ces ions. Dans le complexe argilo-humique, les ions sont étroitement liés : la plante et le complexe ionique se concurrencent pour capter des ions, ce qui entraîne une consommation d'énergie par le végétal.

4.2.1. Modalités. Chez les végétaux supérieurs, les minéraux sont absorbés par les poils absorbants ou les parties non subérifiées de la racine.

En général, les minéraux sont absorbés sous forme d'ions. Certaines substances telles que le fer ont des difficultés à être absorbées à un pH élevé ; l'existence de certains complexes organométalliques, tels que les chélates, permet de résoudre cette problématique. Les ions ne sont pas absorbés indifféremment par les cellules. Il y a une perméabilité sélective qui empêche le Na de pénétrer dans la cellule. En revanche, la concentration du K est plus élevée à l'intérieur qu'à l'extérieur (accumulation).

Pour les cations : NH4 +, K+, Mg2+, Ca2+, Na+

Pour les anions : NO3-, Cl-, SO42-, H2PO4-

4.2.2.Etapes de l'absorption

Deux étapes :

- **L'adsorption,** étape de fixation superficielle, passive et réversible pendant laquelle, l'élément adsorbé peut être désorbé.
- **L'absorption** (au sens strict) qui suit la première étape et peut être active ou passive, selon les ions.

4.2.3. Mécanismes de l'absorption. La température et les inhibiteurs métaboliques influencent l'absorption ; par exemple, une cellule morte ne peut pas absorber. Il existe différentes parties impliquées dans le processus de transport des ions et des molécules de petite taille. Trois façons de pénétrer sont possibles :

La diffusion,

Le transport passif (diffusion facilitée), Le transport de masse.

- **La simple diffusion**. La membrane cellulaire offre la possibilité de pénétrer l'eau et les molécules non polaires par simple diffusion, tout comme quelques petites molécules polaires telles que l'urée, le glycérol et le $CO2$.

  La loi de Fick exprime ce phénomène de diffusion. $(DQ/dT)=k.a.\Delta c$

  k : K correspond au coefficient de diffusion,

  a correspond à la surface de diffusion,

  Δc correspond à la variation de concentration.

L'équilibre de la diffusion est atteint lorsque le gradient de concentration est nul. Les petites molécules sont transportées par deux types de protéines membranaires. Les protéines porteuses et les canaux protéiques sont présents.

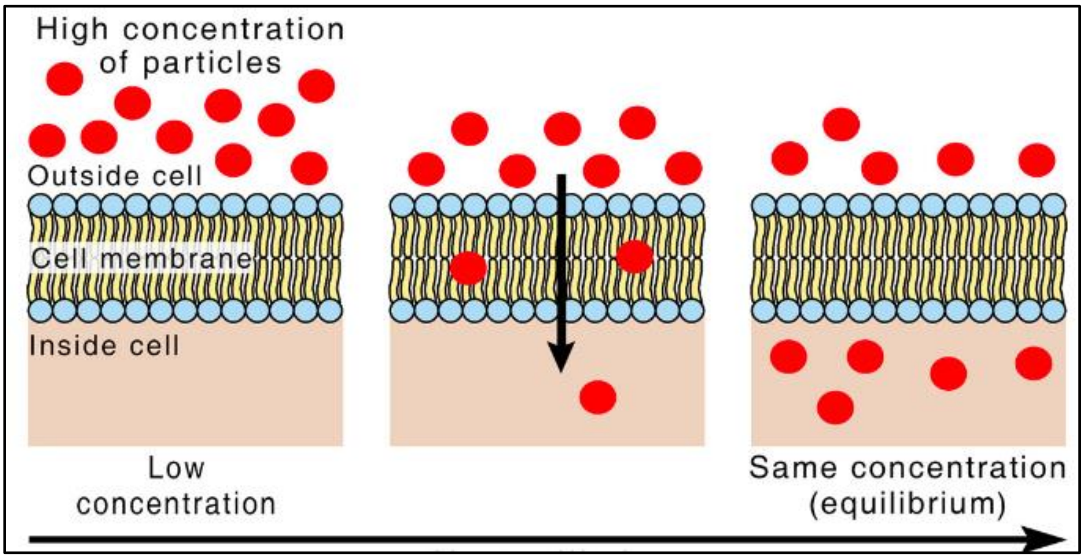

Figure .38. Simple diffusion

- **Le transport passif et la diffusion facilitée**.

  L'acheminement passif et la diffusion simplifiée. L'échange se fait à travers des canaux protéiques et des protéines transporteuses. Lorsque la molécule n'est pas chargée, le gradient de concentration détermine son transport. En cas de charge, le transport de cette molécule est influencé par le gradient de concentration et par le gradient électrochimique. Le transport dans le sens du gradient est donc responsable d'un potentiel de membrane. On plasmolyse une cellule végétale dans une solution hypertonique contenant une forte concentration de saccharose. Une fois quelque temps passé, la cellule retrouve sa turgescence : elle rétablit son hypertonie en absorbant des ions (ou des petites molécules) contre le gradient du potentiel électrochimique. Ce phénomène démontre que la cellule a la capacité de retenir des ions.

Ces mouvements requièrent de l'énergie chimique, comme l'ATP, et physique, comme le gradient ionique, en raison des déplacements d'électrons. Le type le plus fréquemment utilisé est celui des pompes à protons, car cette énergie permet le fonctionnement des pompes ioniques. Deux types de pompes sont présents .

- La circulation est assurée par des pompes rédox, ce qui implique des déplacements d'électrons. Ces pompes génèrent l'ATP.
- Les pompes ATPase sont utilisées pour évacuer les protons de la membrane du plasmalème ou du tonoplasme (transports actifs). Elles font appel à l'énergie. Les ATPases jouent un rôle actif dans le transport des protons.

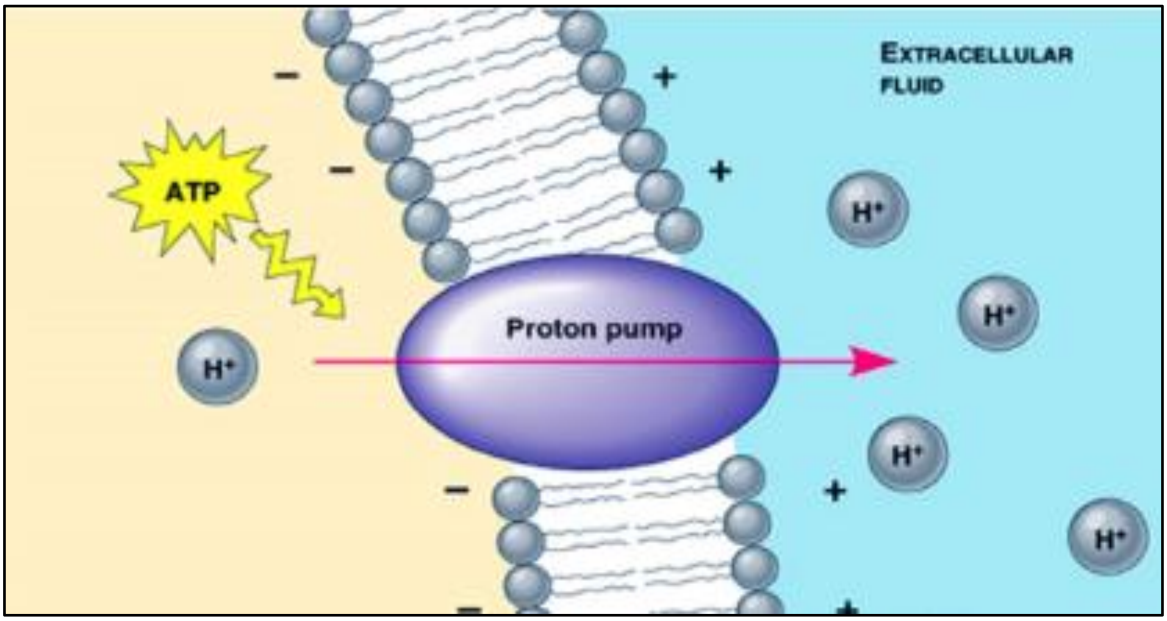

Figure.39. Proton pump

La « force motrice protonique » produite par cette émission de protons permet à son tour d'énergie le mouvement d'autres espèces ioniques. Les transports actifs secondaires sont mentionnés. Ce transport secondaire actif se déroule dans le sens inverse du gradient, ce qui nécessite donc de l'énergie. Si un seul produit est transporté, on parle de système uniport. Il s'agit d'un système symport lorsque deux solutés traversent dans le même sens. La traversée des deux solutés dans un sens différent est considérée comme un transport antiport.

4.3. Rôles des ions dans la plante.

4.3.1. Rôles physiques. L'entrée du magnésium est favorisée par les phosphates, tandis que le calcium l'empêche. Les ions jouent un rôle essentiel dans la préservation de la turgescence, du pH (système tampon), ainsi que dans la génération de potentiels membranaires qui influencent la perméabilité molaire.

4.3.2. Rôles physiologiques. Les composés phosphorylés, tels que les phospholipides, les composés phosphorylés, les nucléotides et les acides nucléiques, jouent un rôle essentiel dans la composition. Le soufre est présent dans les acides aminés et les protéines. Le calcium est présent dans les parois où les peptides se combinent pour former des pectates ; dans la vacuole, il se présente sous forme de cristaux d'oxalate de calcium ; dans le cytoplasme, il est lié à la calmoduline.

Le fer (Fe) est présent dans les hèmes et les cytochromes. Le calcium est présent dans les chloroplastes (en plastocyanines) et dans les mitochondries où ils sont responsables de la production des cytochromes oxydases. Les nitrates-réductases et les nitrogénases contiennent du molybdène.

La quantité de phosphore est élevée pendant la floraison et dans les graines. Le potassium joue un rôle dans la transformation des glucides. Le calcium est principalement présent dans les endroits où les produits toxiques sont stockés (généralement dans des vacuoles).

4.4. Les macronutriments ou macroéléments

Il s'agit des minéraux les plus présents dans les cellules végétales. L'azote, le potassium, le phosphore, le calcium, le magnésium et le soufre sont parmi ces minéraux

- **L’azote** le principal composant des molécules indispensables à la formation des cellules végétales. L'azote est nécessaire à la formation des acides nucléiques (ARN, ADN), des acides aminés, des nucléotides, des coenzymes et de la chlorophylle. L'azote dans le sol est étroitement lié au taux de protéines des fruits.
- **Le potassium** cet ingrédient alimentaire joue un rôle dans l'ouverture des stomates. Grâce au potassium, les sels minéraux circulent dans les tissus végétaux grâce à l'osmose. Par conséquent, il joue un rôle dans l'équilibre ionique au sein des cellules. Il joue également le rôle d'activateur pour plusieurs enzymes.
- **Le phosphore** Le phosphore se retrouve dans plusieurs molécules essentielles à la vie. Il est présent dans les acides nucléiques, dans les chloroplastes et dans les protéines du noyau. Il se trouve dans les molécules d'énergie ATP (adénosine triphosphate) et ADP (adénosine diphosphate). Les cellules végétales jouent donc un rôle énergétique, plastique et génétique grâce au phosphore.
- **Le calcium** occupe une place essentielle dans les parois cellulaires, assure la cohésion des parois cellulaires en les liant les unes aux autres. Il joue un rôle dans l'ouverture de la membrane en permettant le transport de certaines substances et en particulier celle d'autres.

La présence de calcium est indispensable pour le bon fonctionnement de certaines enzymes comme la calmoduline.

- **Le magnésium** L'atome central de la chlorophylle, le magnésium, joue un rôle essentiel dans la photosynthèse. De nombreuses enzymes sont activées par le magnésium, y compris deux enzymes essentielles : la ribulosbiphosphate carboxylase (RuBisCO) et la phosphoenolpyruvate carboxylase (PEPC).
- **Le soufre** présent dans les acides aminés sont la cystine, la cystéine et la méthionine, joue un rôle essentiel dans la création des nodules indispensables à la fixation de l'azote atmosphérique chez les légumineuses, il favorise la résistance des plantes aux maladies, joue un rôle dans le développement des plantes et dans la production de fruits. Si le soufre est insuffisant, les feuilles des plantes sont d'un vert pâle.

4.5. Les micronutriments ou oligoéléments

Malgré leur faible présence, les micronutriments ou oligo-nutriments restent néanmoins essentiels. Le chlore, le cuivre, le bore, le molybdène, le fer, le manganèse, le zinc et le nickel sont parmi eux.

- **Le fer** joue un rôle crucial dans la synthèse de la chlorophylle. Il est le composant essentiel de la synthèse des cytochromes (pigments) et de l'enzyme nitrogénase. Il n'est pas fréquent que les sols manquent de fer. Cependant, il est possible que cet élément ne soit pas disponible pour les plantes si le pH ne se situe pas entre 5 et 6,5.
- **Le zinc** sont présents dans la composition de nombreuses enzymes végétales, joue également un rôle dans l'activation de plusieurs enzymes. Cet oligoélément joue un rôle dans la production de chlorophylle.
- **Le bore** Le transport des hydrates de produits carbonés lors de la photosynthèse est l'un des rôles de cet oligoélément. Il est également impliqué dans la régulation des protéines végétales. L'emploi du calcium, tout comme la production des acides nucléiques, nécessite le bore. L'intégrité de la membrane plasmique est garantie par le bore.
- **Le cuivre** L'activateur et le composant des enzymes impliqués dans les réactions d'oxydoréduction dans les cellules végétales sont le cuivre, ce minéral joue un rôle crucial dans l'organisme en tant que composant essentiel d'enzymes. Ces enzymes comprennent les enzymes responsables de l'absorption de l'azote.
  • **Le molybdène** joue un rôle dans la dégradation de l'azote et la diminution des nitrates. Les molybdènes sont très peu nécessaires aux plantes (moins de 50 grammes par hectare).

- Le chlore joue un rôle essentiel dans la formation de l'osmose et l'équilibre ionique au sein des cellules animales. Il participe également aux processus photosynthétiques.

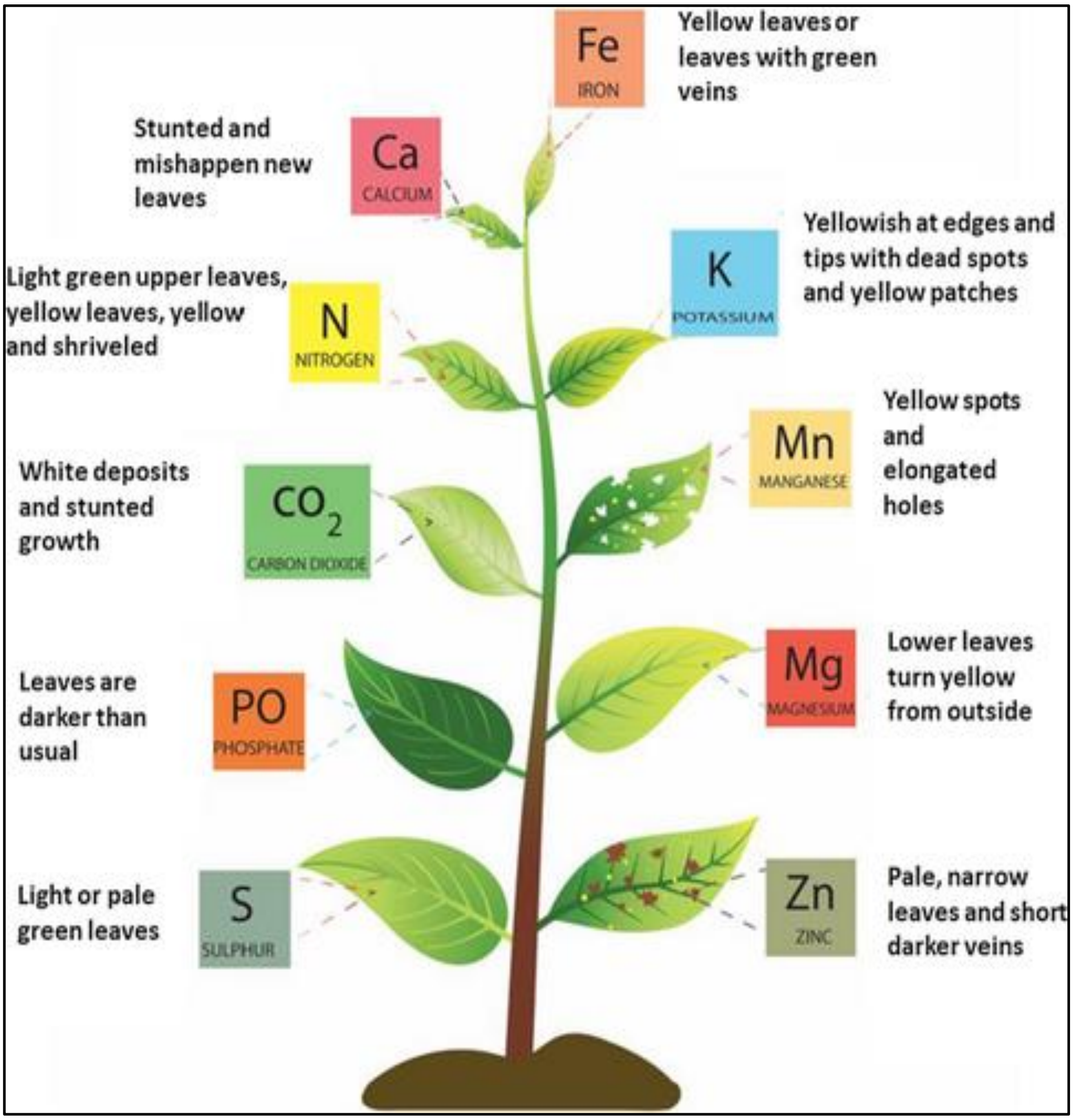

Figure .40. Mineral deficiencies in plants

Table.1. Plant mineral requirements

Elements	**Chemical symbols**	**Functions**	**Signs of deficiency**	**Signs of excess**
Macro elements				
Azote	**N**	Constituent of chlorophyll, vitamins, DNA, etc.	Plants turn pale green, older leaves leaves turn yellow	Exaggerated growth
Potassium	**K**	Maintaining cellular cellular organization	Brown spots on leaves, growth reduced	Leaves become paler and become covered with dark spots
Calcium	**Ca**	Growth and strength of membrane	Premature leaf and leaves and flowers	Decreases solubility of certain elements, thus deficiency
Phosphore	**P**	Constituent DNA, proteins,enzymes, etc.	Leaves turn dark green or green	Yellowing and browning of leaf tips then leaf drop
Magnésium	**Mg**	Constituent of chlorophyll, production energy production	Leaves curl and yellowing	Exaggerated growth of stems and roots, Decrease flowering
Soufre	**S**	Constituent of several enzymes	Young leaves turn turn yellow first	Leaves are bluish bluish green and curve towards inward
Trace elements				
Fer	**Fe**	Formation of chlorophyll	Yellowing of Leaves	Rarely toxic
Chlore	**Cl**	Involved in photosynthesis	Yellowing of tomato leaves	Tobacco produces black ash
Manganèse	**Mn**	Training for chlorophyll	Yellowing of young then leaf fall	Induces iron deficiency resulting

				in yellowing of leaves
Bore	**B**	Important for growth	Diseases physiological (e.g : cracking of celery celery stalks, brown spots on cauliflower)	Yellowing of sides of leaf, then drop
Zinc	**Z**	Activates a large enzymes	Irregular growth, stunted leaves	Leaf yellowing leaves, bud death bud death

4.6.Quelques particularités.

En présence de calcium, deux types de plantes sont présents :

- Les plantes calcicoles, qui peuvent supporter ou tolérer le calcium. Lorsque la teneur en calcium augmente, le pH augmente également (solution basique).
- Les produits qui ne peuvent pas absorber le calcium, leur teneur en calcium diminue, ce qui entraîne une baisse du pH (acidification). Les plantes calcicoles ont la capacité de modifier la structure de leur membrane afin de restreindre l'absorption de Ca.
- Le fer ne peut pas être absorbé sur un sol basique, car il est précipité.
  Il existe des plantes halofuges (résistantes au sel) et des plantes halophiles (les halophytes) qui sont sensibles au sel. Ces organismes halophytes se développent dans les eaux saumâtres ou à proximité de la mer (des eaux salées). Ces plantes ont l’aspect de plantes grasses.

Chapter 5: Nitrogen nutrition

(Nitrogen cycle, nitrate transport and assimilation)

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Introduction

Nitrogen plays a crucial role in the proper functioning of plants. In their nitrogen cycle, organic nitrogen is present in nucleic acids, proteins, cofactors, ATP, and some pigments. Alkaloids are secondary compounds derived from nitrogenous compounds that function to protect the plant. Notable examples include morphine, heroin, cocaine, and caffeine. The soil contains mineral nitrogen in the forms of nitrate (NO_3^-) and ammonium (NH_4^+). The atmosphere also contains a large amount of nitrogen (80%) as N_2, which can be oxidized to N_2O (nitrous oxide). Plants absorb carbon, which allows them to convert mineral matter into organic matter. Most plants are also autotrophic for nitrogen.

5.1. Forms of Nitrogen in Minerals

Organic or mineral nitrogen constitutes about 1 to 5% of dry matter. Nitrogen is present in proteins, which have an average nitrogen content of 16%. By measuring nitrogen, we can estimate protein content. Nucleic acids, coenzymes, vitamins, and hormones also contain nitrogen. When nitrogen is in its mineral form, it appears as ionic forms such as NH_4^+ or NO_3^-.

5.2. Different Forms of Nitrogen Available in the Biosphere

- **Atmospheric Nitrogen**: Occupying 78% of the air, it is the primary source. However, only certain plants in symbiosis (with bacteria or algae) can directly utilize atmospheric nitrogen.
- **Soil Nitrogen**:
    - In its outer layer, nitrogen has five electrons, three of which are unpaired and can form covalent bonds. Nitrogen's oxidation state ranges from –3 to +5.
    - Mineral nitrogen is present in three forms: NO_3^-, NO_2^-, NH_4^+. Complex nitrogen-containing molecules can be proteins or amino acids, primarily found in humus. Plants use nitrogen from decomposed organic matter.

5.3. Nitrogen Assimilation

The conversion of atmospheric N_2 to ammonium is mainly achieved through biological nitrogen fixation, which is a crucial entry point for molecular nitrogen into the nitrogen biogeochemical cycle.

5.3.1. Atmospheric Nitrogen Assimilation: Symbiosis

Atmospheric nitrogen can be converted to ammonium by certain bacteria. Typically, these nitrogen-fixing prokaryotes live independently in the soil, but some form symbioses with higher plants. In these symbioses, the prokaryote directly supplies mineral nitrogen to the host plant in exchange for other nutrients and carbohydrates. Such symbioses occur in nodules formed on plant roots that house the nitrogen-fixing bacteria. The most common symbiosis is between Fabaceae (Leguminosae) and soil bacteria of the genera Azorhizobium, Bradyrhizobium, Photorhizobium, Rhizobium, and Sinorhizobium (collectively known as rhizobia).

a) - Types of Nitrogen-Fixing Microorganisms

- **Free-Living Fixators**:
    - These reside in the soil and produce humus upon death, which plants then use. Aerobic bacteria such as Azotobacter are carbon heterotrophs. Anaerobic bacteria like Clostridium are also present.
- **Carbon Autotrophs**:
    - There are photo-anaerobic bacteria with a photosystem similar to Rhodospirillum, and cyanobacteria such as Nostoc and Anabaena.
- **Azospirillum**:
    - This substance can fix nitrogen freely in the rhizosphere of maize plants.
- **Symbiotic Fixators**:
    - Carbon heterotrophs include rhizobial bacteria (anaerobes) and actinomycetes (e.g., Frankia) that parasitize woody plants. Cyanobacteria such as Nostoc and Anabaena, as well as liverworts, ferns, cycads, and Gunnera, are among other carbon fixers.
    - A nodule is a distinct organ in the plant where nitrogen-fixing bacteria develop. These bacteria irreversibly transform into bacteroids, which fix nitrogen.

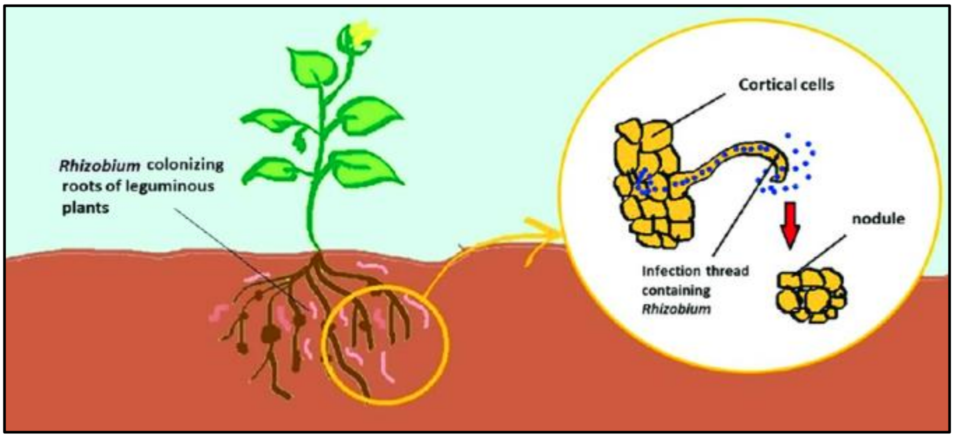


Figure.41. Nitrogen fixation in leguminous plants by rhizobium.

3.2. Host/Symbiont Association

Legumes and rhizobia are not inherently in symbiosis. Legume seedlings may not associate with rhizobia and can remain unassociated throughout their entire life. Rhizobia are also present in the soil as free-living organisms. However, in situations where nitrogen is limited, symbionts seek each other out through a complex exchange of signals. This signaling, resulting infection, and the formation of nitrogen-fixing nodules involve specific genes in both the host and the symbionts.

The plant genes specific to nodules are known as Nod genes. The migration of nitrogen-fixing bacteria to the roots of the host plant is the first step in establishing the symbiotic relationship between the nitrogen-fixing bacteria and their host. The roots secrete chemical attractants, including (iso)flavonoids and betaines, which are responsible for this migration. The rhizobial protein NodD is activated by these attractants, leading to the transcription of other nodule genes.

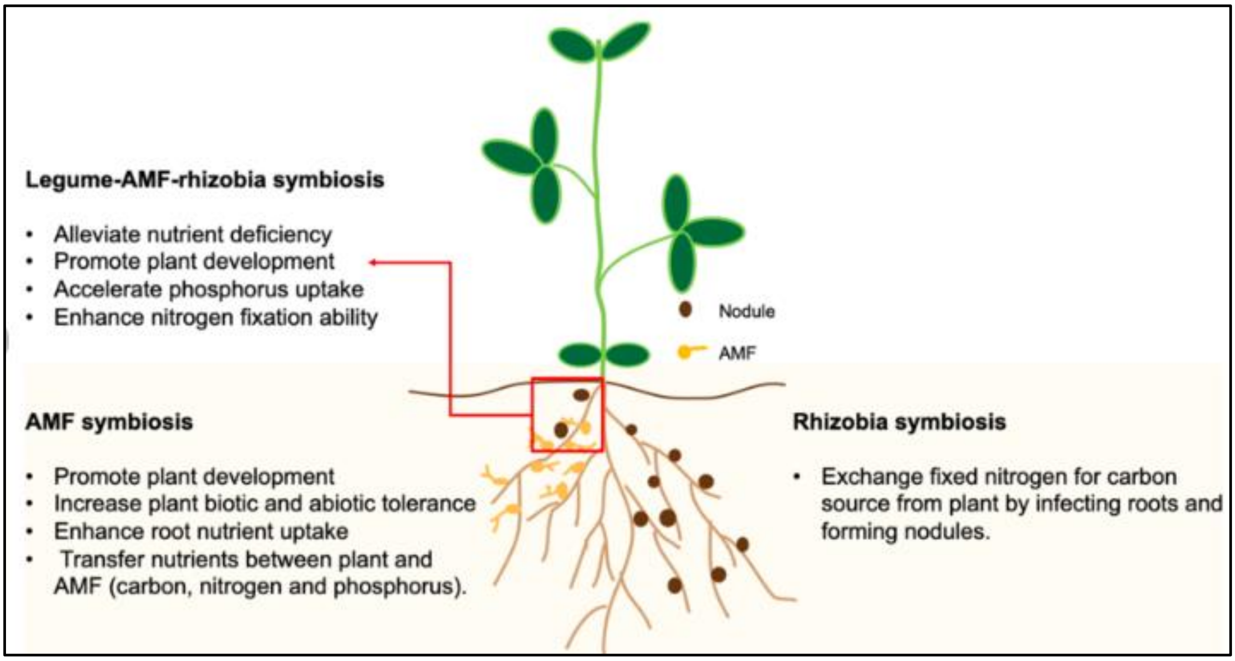


Figure.42. The impact of symbiosis with mycorrhizal fungi

The Process

The formation of root nodules involves two simultaneous processes: infection and nodule organogenesis.

a) **Infection**: Rhizobia that attach to the root hairs produce Nod factors, which cause significant curling of the root hair cells.

b) The rhizobia then colonize the small space created by the root cells. Bacterial cells can access the external surface of the plant's plasma membrane by degrading the cell wall of the root hair in these regions, also in response to Nod factors.

c) **Infection Thread**: This is an internal tubular extension of the plasma membrane that forms when vesicles derived from the Golgi apparatus fuse at the infection site.

d) At its tip, the thread forms by fusing secretory vesicles at the end of the tube. Cortical cells differentiate deeper into the root cortex, near the xylem, and begin to divide, creating a zone within the cortex, known as the nodule primordium, from which the nodule develops.

e) Proliferating rhizobia extend through the root hair and cortical cell layers towards the nodule primordium. Upon encountering specialized cells inside the nodule, the infection thread fuses with the plasma membrane of the host cell, releasing bacterial cells enclosed in a membrane derived from the host cell's plasma membrane.

f) Initially, the bacteria continue to divide, and the surrounding membrane surface area increases to support their growth by fusing with smaller vesicles. Shortly thereafter, at an undetermined time, the bacteria stop dividing and begin to expand and differentiate into nitrogen-fixing endosymbiotic organelles known as bacteroids.

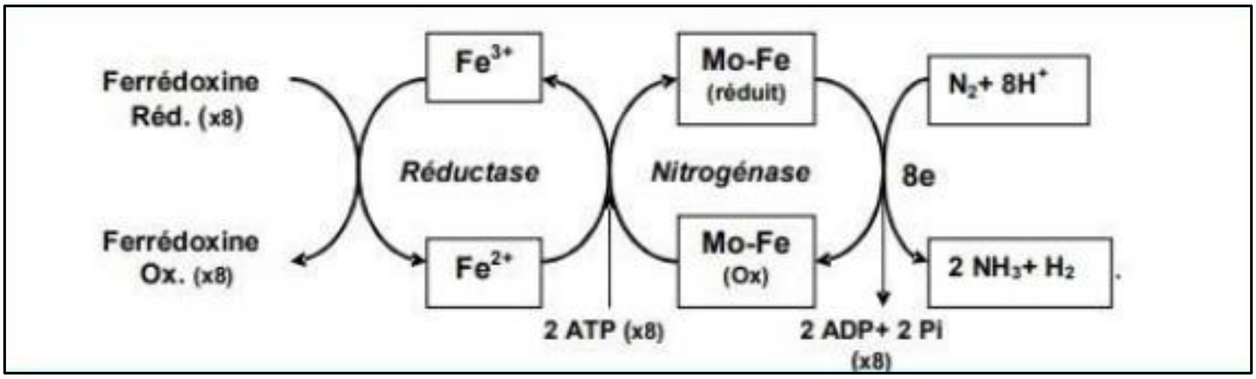


Figure.43. Reduction of nitrogen gas to ammonium

5.3.2. Nitrogen Fixation and Assimilation

In the presence of ATP, which provides the activation energy for the N_2 fixation reaction, and a powerful reductant, atmospheric nitrogen is reduced to ammonium. Ferredoxin is the primary source of reduction in most nitrogen-fixing microorganisms. Two protein catalysts are involved in this reaction: a reductase, also known as nitrogenase, which provides the electrons, and a nitrogenase enzyme that uses these electrons to reduce nitrogen.

Ammonia is produced through biological nitrogen fixation from molecular nitrogen. This reaction is catalyzed by the nitrogenase enzyme complex, consisting of the Fe protein and the MoFe protein.

Ammonia released by symbiotic nitrogen-fixing prokaryotes must be quickly converted into organic forms in the root nodules before being transported to the shoot via the xylem. Based on the composition of the xylem sap, nitrogen-fixing legumes can be classified as either exporters of amides or ureides. Temperate legumes, such as peas (Pisum), clover (Trifolium), broad beans (Vicia), and lentils (Lens), export amides (mainly asparagine or glutamine). Tropical legumes, such as soybeans (Glycine) and common beans (Phaseolus), export ureides. Citrulline, allantoine, and allantoic acid are the three main ureides.

Ultimately, these compounds are released into the xylem and transported to the shoot, where they are rapidly converted into ammonium.

5.3.3. Assimilation of Mineral Nitrogen:

Assimilation of Nitrates and Nitrites: The energy required to reduce nitrates mainly comes from photosynthesis. Two successive reactions, catalyzed by two enzymes, reduce the oxidation state of nitrate (V) to ammonium (III).

- **Nitrate Reductase (NiR):** This enzyme reduces nitrates to nitrites. Its sensitivity to light and hormones (cytokinins) varies. NiR is located outside the chloroplast and is part of an enzymatic complex where NADPH and H^+ are used as electron donors, with FAD as the cofactor. The reaction for nitrate reduction is:

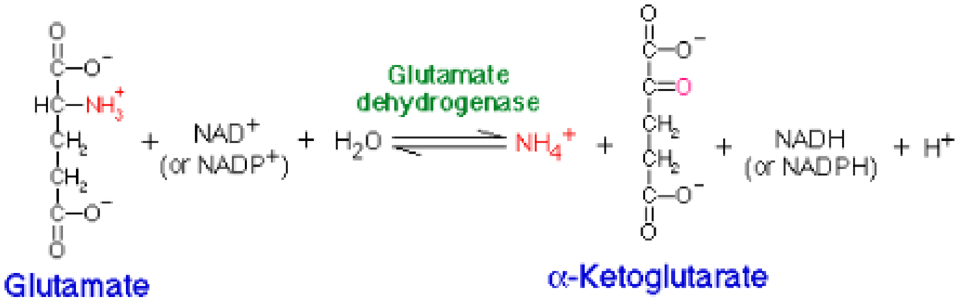
  NO3−+NAD(P)H+H+→NO2−+NAD(P)++H2O\text{NO}_3^- + \text{NAD(P)H} + \text{H}^+ \rightarrow \text{NO}_2^- + \text{NAD(P)}^+ + \text{H}_2\text{O}NO3−+NAD(P)H+H+→NO2−+NAD(P)++H2O

- **Nitrite Reductase:** Found inside the chloroplast, this enzyme converts nitrite to ammonium. Reduced ferredoxin, also known as NADPH, H^+, acts as the electron donor. The overall reaction is:

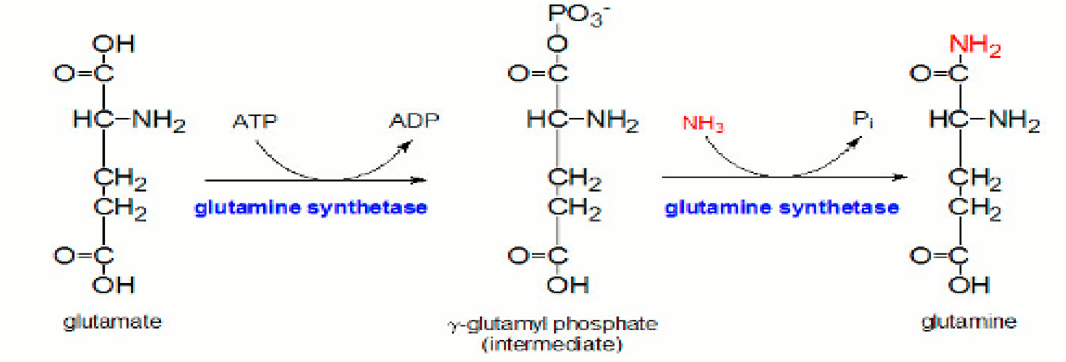
  NO2−+72NAD(P)H+H+→NH4++72NAD(P)++2H2O\text{NO}_2^- + \frac{7}{2} \text{NAD(P)H} + \text{H}^+ \rightarrow \text{NH}_4^+ + \frac{7}{2} \text{NAD(P)}^+ + 2 \text{H}_2\text{O}NO2−+27NAD(P)H+H+→NH4++27 NAD(P)++2H2O

Nitrate is readily absorbed by roots due to its assimilatory reduction. Ammonium, which can be produced by biological nitrogen fixation, nitrate reduction, or direct absorption of ammonium ions, is generally toxic to most organisms. However, it is beneficial for cultivating crops like corn, yellow tomatoes, and rice. To be absorbed, ammonium must be converted into non-toxic amines or amides. The assimilation of ammonium involves three successive enzymes:

- **Glutamate Dehydrogenase:** This allosteric enzyme facilitates the absorption of ammonia into the body and the catabolism of amino acids. It is present in all living organisms: in mitochondria (for animals) and in chloroplasts (for plants).



- **Glutamine synthetase**, which promotes ammonia uptake in the presence of energy thanks to ATP's energy-rich phosphate bond.



- **Glutamate Synthase:** Along with glutamine synthetase, glutamate synthase plays a crucial role as a precursor in the synthesis of purines and pyrimidines, as a regulator of protein turnover, and as an intermediary in gluconeogenesis and acid-base balance. Nitrogen is absorbed through the biosynthesis of enzymatic proteins, structures, and reserves. Due to its positive charge, ammonium is poorly absorbed by plants, which promotes its fixation on soil minerals. Plant roots must be very close to ammonium to absorb it. Most ammonium is converted into nitrate by soil microorganisms before being absorbed by the root system, a process known as nitrification.

Nitrification takes one to several weeks and varies with temperature. The soil also contains another portion of ammonium in the form of organic matter and microbial biomass, which will be mineralized according to the plants' needs.

5.4. Nitrogen Cycle:

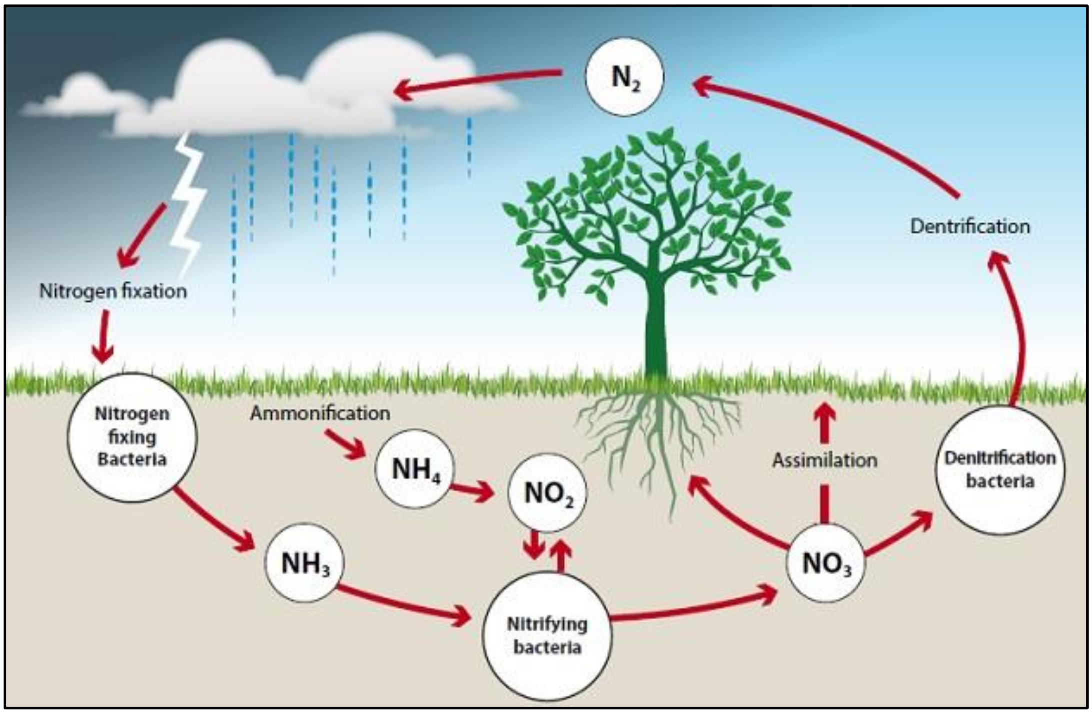


Figure .44. Nitrogen cycle

Chapitre 6 : Nutrition carbonée (La photosynthèse)

Chapter 6: Carbon nutrition (Photosynthesis)

Introduction

Photosynthesis is a fundamental characteristic of plants, providing them with autonomy from other life forms. It harnesses solar energy to decompose water molecules into their components: oxygen, which is released as a byproduct, and hydrogen, which forms a "driving force" for converting atmospheric carbon dioxide into sugars.

6.1. General Overview

6.1.1 Definition:

Photosynthesis is the process by which plants convert light energy into chemical energy, producing organic matter (sugars) from sunlight. This process occurs in chloroplasts, specialized cellular organelles, and involves the use of carbon dioxide and water to generate oxygen and organic molecules such as glucose. Photosynthesis is divided into two main stages: the light-dependent reactions and the Calvin cycle (light-independent reactions).

The light-dependent reactions, or the "light phase," rely on light energy and involve the transport of electrons through two photosystems (PSI and PSII) to produce ATP (the energy carrier molecule) and NADPH + H+ (a reducing agent). This phase directly converts light energy into chemical energy.

The Calvin cycle, also known as the "dark phase," is an entirely enzymatic process independent of light. During this phase, ATP and NADPH + H+ are used to convert carbon dioxide and water into carbohydrates. This phase facilitates the absorption of carbon dioxide.

6.1.2 Chemical Equation:

The general formula for photosynthesis can be expressed as:

nCO2+nH2O+light energy→(CH2O)n+nO2+nH2OnCO_2 + nH_2O + \text{light energy} \rightarrow (CH_2O)_n + nO_2 + nH_2OnCO2+nH2O+light energy→(CH2O)n+nO2+nH2O

It is now understood that the sugar produced contains three carbon atoms (3-phosphoglyceraldehyde, a C3 sugar), resulting in the formation of carbon dioxide and water from carbohydrates:

3CO2+6H2O+light energy→C3H6O3+3O2+3H2O3CO_2 + 6H_2O + \text{light energy} \rightarrow C_3H_6O_3 + 3O_2 + 3H_2O3CO2+6H2O+light energy→C3H6O3+3O2+3H2O

6.1.3 Location :

Photosynthesis primarily occurs in the leaves, specifically within the palisade mesophyll tissues located beneath the upper epidermis, which absorb light photons. Chloroplasts within these cells contain light-absorbing pigments, including chlorophyll and accessory pigments, which endow them with the capability for photosynthesis.

6.1.3.1 The Chloroplast:

The center of photosynthesis is the chloroplast, a semi-autonomous organelle within plant cells that possesses its own genetic material, similar to mitochondria. Chloroplasts have a double phospholipid membrane system (outer and inner membranes):

- The **outer membrane** is composed of phospholipids and proteins, characteristic of biological membranes, and is relatively permeable.
- The **inner membrane** is less permeable and is organized into structures known as thylakoids. These thylakoids can be stacked to form grana (singular: granum) or exist as isolated thylakoids in the stroma. The primary site of photosynthesis is the inner membrane, which defines the internal part of the chloroplast known as the stroma. Unsaturated fatty acids in the membrane maintain its fluidity, while pigments (chlorophyll and carotenoids) are often associated with proteins. The formation of pigment-protein complexes is facilitated by transmembrane structures known as photosystems (PSI and PSII).

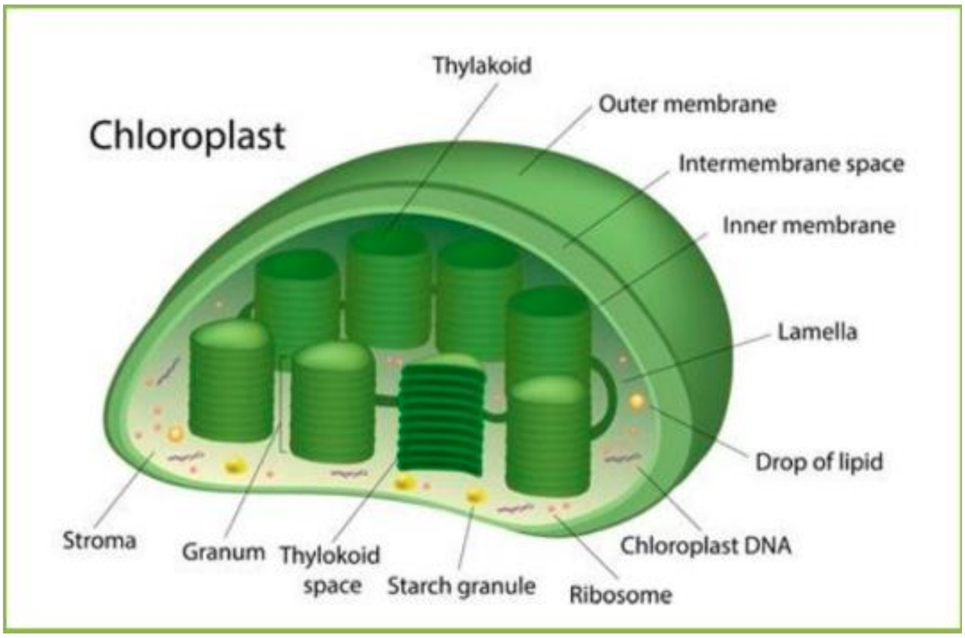


Figure.45. Diagram of a chloroplast

6.1.3.2. Chlorophyll: The Photosynthesis Pigment

Chlorophyll belongs to the heme group and features a tetrapyrrole ring structure containing a magnesium (Mg^{2+}) atom. Chlorophyll "a" (with a methyl radical) and chlorophyll "b" (with an aldehyde radical) each have distinct side chains: chlorophyll "a" has a shorter side chain, while both types have a long hydrophobic phytol chain (a hydrocarbon derived from isoprene, C20). As a pigment, chlorophyll has the ability to absorb light in the visible spectrum, but absorption levels vary between chlorophyll types. Chlorophyll "a" primarily absorbs light at wavelengths of 430 nm (blue) and 660 nm (red), whereas chlorophyll "b" absorbs light at approximately 450 nm and 643 nm.

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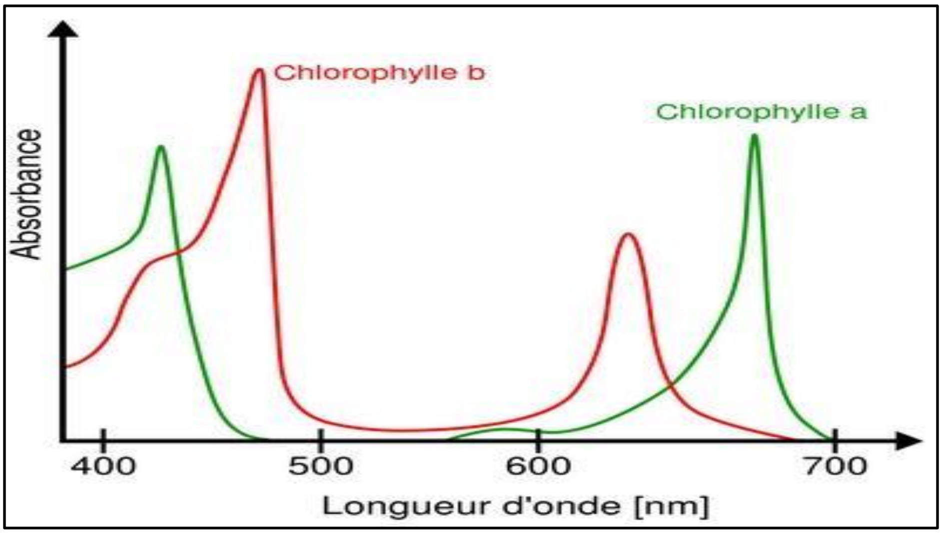

Figur.46. Absorption spectrum of chlorophylls a and b

When a pigment absorbs a photon at its absorption capacity, one of its electrons moves to an excited state. This energy can be transferred in three ways: by emitting it as a photon, by dissipating it as heat (both methods result in energy loss), or by resonance transfer with minimal energy loss.

It is important to note that only chlorophyll "a" is "active" in photosynthesis and is always associated with other pigments known as accessory pigments. These accessory pigments absorb photons at shorter wavelengths (higher energy) than those absorbed by chlorophyll and then transfer the energy to chlorophyll at longer wavelengths (lower energy). This creates a "donor-acceptor" system. Examples include phycobilins in cyanobacteria and red algae, and carotenoids in higher plants and brown algae. Carotenoids absorb yellow-orange and blue light, while phycobilins absorb green and blue light.

6.1.3.3. Structure of Photosystems:

The photoreceptor centers located in the thylakoid membranes within chloroplasts are called photosystems. They consist of a light-harvesting antenna and a reaction center situated at the core of the antenna.

The light-harvesting antenna uses pigments of different colors to capture light energy: chlorophyll a, chlorophyll b, and carotenoids. The reaction center is a specialized area that contains clusters of pigments with a single pair of chlorophyll a molecules capable of transferring electrons to the primary electron acceptor, which is the first acceptor in the electron transport chain.

In Photosystem I (PSI), the primary electron acceptor is chlorophyll a0, also known as modified chlorophyll a. In Photosystem II (PSII), the primary electron acceptor is pheophytin. Electrons are transported from molecule to molecule via the electron transport chain, leading to an increase in potential.

The main distinction between Photosystem I and Photosystem II is their absorption wavelengths, despite both photosystems being equipped with a pair of chlorophyll a molecules in their reaction centers. This difference is attributed to the importance of chlorophyll-binding proteins in determining their physical characteristics.

Thus, Photosystem II (PSII) contains a molecular complex called P680, while Photosystem I (PSI) contains a molecular complex called P700. During the light-dependent reactions, water initially provides electrons to Photosystem II (PSII), and these electrons are then passed to Photosystem I (PSI). Essentially, photosynthesis is initiated by Photosystem II.

b- Mechanism of Photosystems

Photosystem II (PSII): The light-harvesting antenna first absorbs light energy and then transfers it to the P680 complex. The electrons released from chlorophyll a in the P680 complex are captured by the primary electron acceptor (chlorophyll a0 = modified chlorophyll a) and transported through the electron transport chain. These electrons then pass through the cytochrome complex, causing the transfer of protons from the stroma to the thylakoid lumen. This creates a proton gradient, which drives ATP synthesis by ATP synthase. The electrons eventually leave the cytochrome complex to enter Photosystem I (PSI).

Chlorophyll a in P680 loses electrons that it needs to replace; these electrons are provided by the photolysis of water.

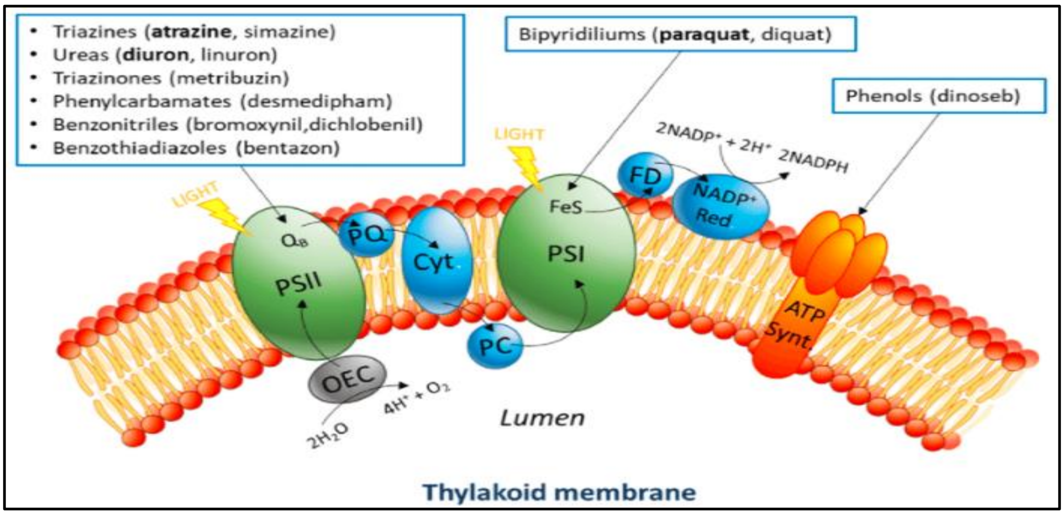

Figure .47. Schematic representation of photosystem II in the thylakoid membrane.

Photosystem I (PSI)

To continue the process of photosynthesis, it is essential to absorb additional light energy, which is transferred by the light-harvesting antenna to the P700 complex. The electrons transmitted by the cytochrome complex are energized by the P700 complex. The primary electron acceptor (phaeophytin) captures these energized electrons and transports them through the electron transport chain to ferredoxin. Ferredoxin then transfers these electrons to NADP+ reductase, which converts NADP+ into NADPH + H+.

Two electrons are lost by the chlorophyll a in P700, and these need to be replaced to ensure the proper functioning of the system. These replacement electrons are supplied by Photosystem II (PSII).

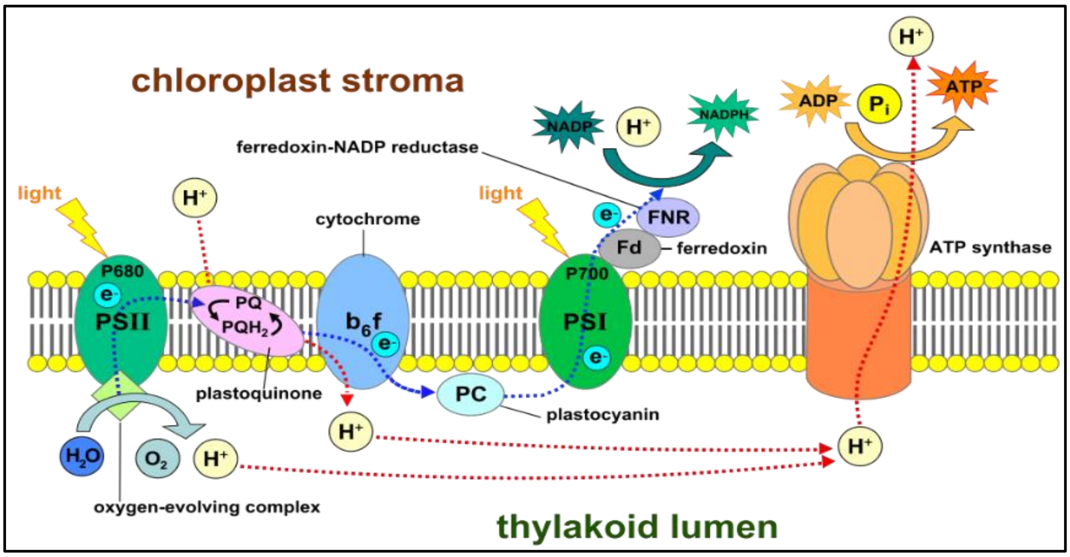

Figure.48. Functioning of the PSI in place in the thylakoid membrane.

6.2. Photosynthesis and Environmental Factors

6.2.1. Metabolic Reactions

6.2.1.1. Electron Transport in the Light Phase

The process of water photolysis and the non-cyclic electron transport at PSII are crucial steps in photosynthesis. During each photo-oxidation event at PSII, water donates an electron to compensate for the one lost by PSII, facilitating its regeneration. Thus, water is the primary electron donor in photosynthesis. For this to happen, water must undergo oxidation under the influence of light, resulting in the release of electrons, protons, and oxygen.

PSII captures the electrons, while the protons produced are accumulated in the thylakoid lumen, contributing to the proton gradient. Oxygen is released into the atmosphere as a byproduct. During these transfers, electrons lose some energy, which is utilized by certain carriers to transport H+ protons from the stroma (extra-thylakoid space) to the thylakoid lumen.

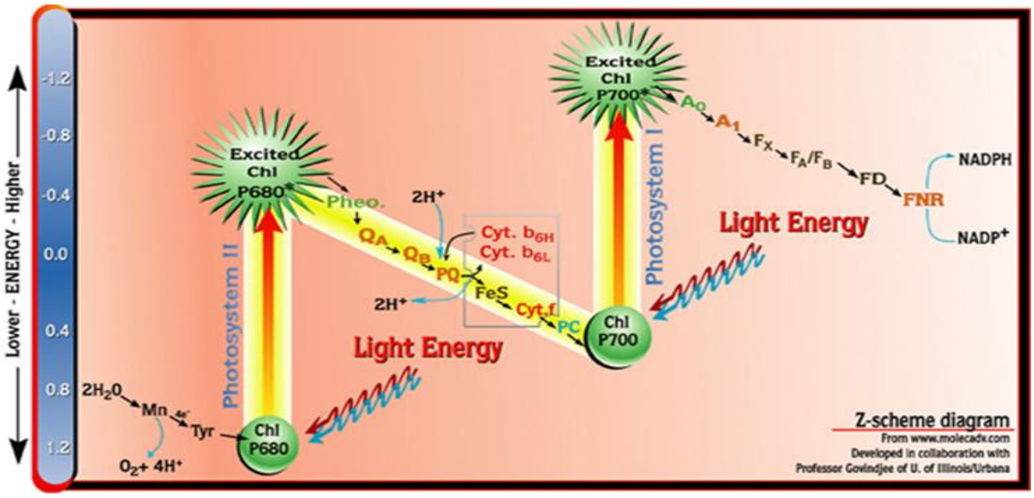

Figure.49. Z” pattern, acyclic electron transfer .

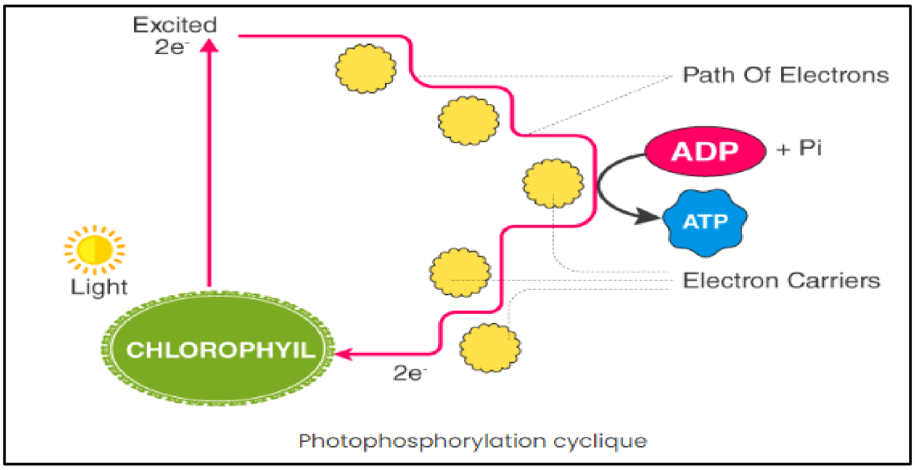

Figure.50. Membrane enzymes and electron transport proteins of non-cyclic photophosphorylation

6.2.1.2. Cyclic Electron Transport

Cyclic electron transport involves only the photosystem. Instead of supplying electrons to NADP+ reductase, ferredoxin transfers them to plastoquinone (PQ) through a cytochrome. The initial chain of carriers then returns the electrons to photosystem I, filling the gaps left behind. This cyclic process (Fig. 18) promotes the accumulation of additional protons in the thylakoid lumen, enhancing ATP production without reducing NADP+ levels, and pushing ATP towards the stroma.

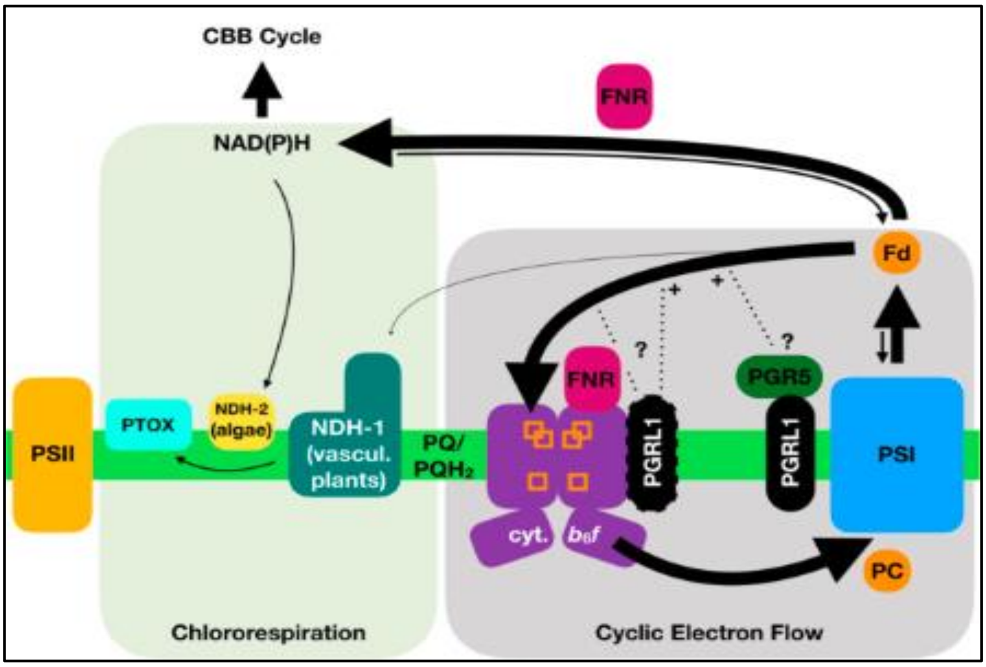

Figure.51. Cyclic electron transfer around the PSI.

6.3. Mechanisms of the Dark Phase

The dark phase, also known as the Calvin cycle, utilizes the energy molecules generated during the light phase and occurs cyclically in the stroma of the chloroplast. The cycle comprises four main steps, three of which are part of the Calvin cycle:

- **CO2 Fixation**: RuBP (ribulose-1,5-bisphosphate), a 5-carbon molecule, reacts with CO2. The enzyme Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase) catalyzes this reaction, forming an unstable 6-carbon intermediate that quickly splits into two molecules of 3-phosphoglycerate (3-PGA), each with 3 carbons.

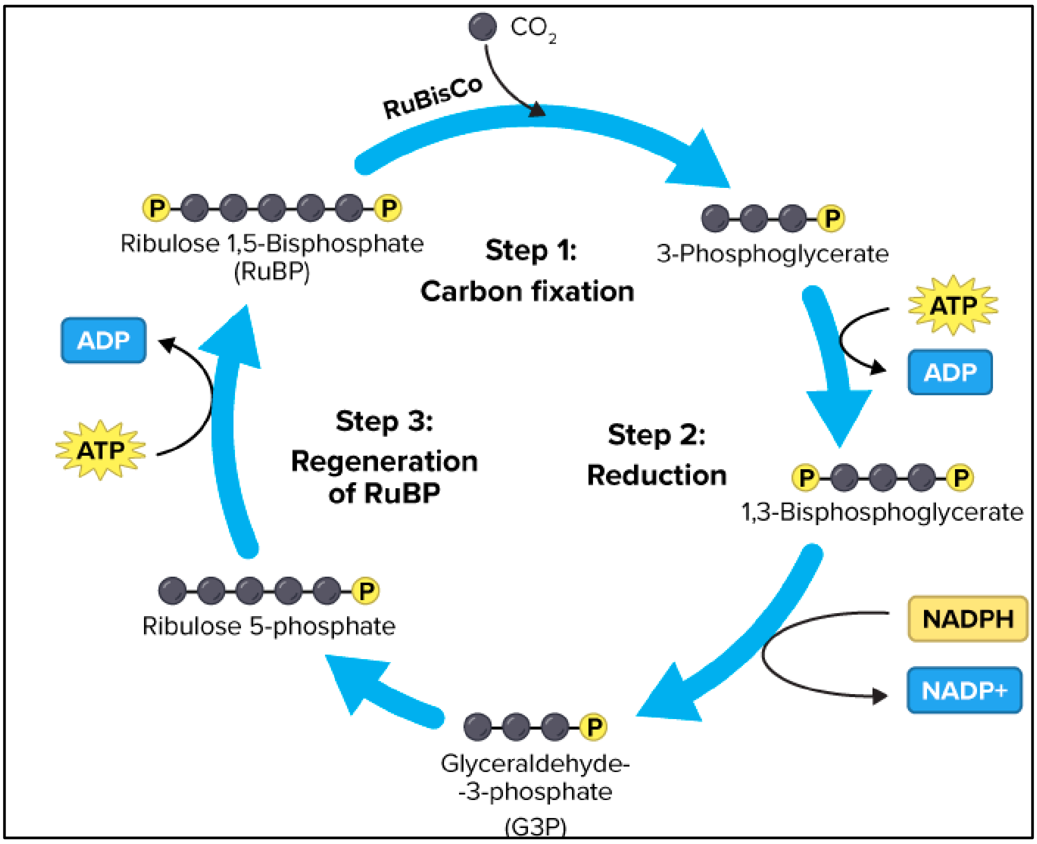

Figure.52. Calvin cycle

- **Effectiveness of Rubisco**

Rubisco, or ribulose-1,5-bisphosphate carboxylase/oxygenase, has two main catalytic functions:

1. **Carboxylase Activity**: This function involves the fixation of CO2, where Rubisco catalyzes the formation of two molecules of 3-phosphoglycerate (3-PGA) from ribulose-1,5-bisphosphate (RuBP).
2. **Oxygenase Activity**: This function leads to the production of one molecule of phosphoglycolate and one molecule of 3-PGA by reacting RuBP with O2.

The oxygenase activity can inhibit the Calvin cycle, making it important to understand under what conditions each function predominates. Rubisco’s carboxylase activity is generally favored due to its higher affinity for CO2 compared to O2. However, since the atmosphere contains more O2 than CO2, Rubisco can often engage its oxygenase function. The enzyme's activity also varies with temperature. The ratio of Rubisco's oxygenase to carboxylase activity changes with temperature due to differential effects on CO2 and O2 solubility. In cooler temperatures, Rubisco tends to favor CO2 fixation.

- **Carbon Reduction**

In the next step of the Calvin cycle, 3-PGA is phosphorylated by ATP to form 1,3-bisphosphoglycerate, which is then reduced by NADPH to produce glyceraldehyde-3-phosphate (G3P), a sugar.

- **Regeneration of CO2 Acceptor**

One-sixth of the G3P produced can be used by the cell for carbohydrate synthesis, while the remaining five-sixths are used to regenerate RuBP. This regeneration process involves several steps and requires ATP.

- **Sugar Synthesis**

As previously mentioned, one-sixth of the G3P produced in the Calvin cycle is involved in plant metabolic reactions, primarily converting into carbohydrates:

- **Transport Form**: Sucrose (α-Glu-Fruct), which is transported in the phloem.
- **Storage Form**: Starch (α-1,4-Glu).

Summary:

- Six turns of the cycle are needed to produce one hexose sugar.
- To convert 12 molecules of 3-PGA into 1,3-bisphosphoglycerate, 12 ATP molecules are required.
- 12 NADPH molecules are used to reduce 12 molecules of 1,3-bisphosphoglycerate to glyceraldehyde-3-phosphate.

6.4.Efficiency per Molecule of CO2 Incorporated

To fix one molecule of CO2, 3 ATP and 2 NADPH are consumed. To form one hexose, six CO2 molecules must be fixed, which involves 6 cycles of the Calvin cycle and consumes 18 ATP and 12 NADPH. The efficiency of the process is relatively low.

6.5. Photosynthesis Efficiency

1. $\Delta G°'$ for reducing CO2 to hexose = +114 kcal/mole.
2. For one Calvin cycle turn, 3 ATP and 2 NADPH are required. Since NADP+ reduction to NADPH involves 2 electrons, and 2 NADP+ are needed, 4 electrons are involved.
   - Capturing 4 photons by PS II and 4 photons by PS I (a total of 8 photons), where 1 mole of photons (600 nm) has an energy content of 47.6 kcal.
   - Total energy: $8 \times 47.6 = 381$ kcal.
   - Photosynthesis efficiency: $(114 \times 100) / 381 = 30\%$.

6.6 .Photosynthesis in C3 Plants

6.6.1.Limiting Factors of Photosynthesis

Photosynthesis (both light and dark phases) requires several factors:

- **Water**: Provides electrons for the light phase (water photolysis). It is generally not a limiting factor except in arid climates.
- **CO2**: Essential for the Calvin cycle. The atmospheric CO2 concentration is limited and often the limiting factor.
- **Light**: Essential for the light phase. The light must be within the absorption wavelength range of chlorophyll to be effective.

Factors influencing these elements will directly or indirectly affect photosynthesis efficiency. Thus, actions affecting stomatal opening and CO2 fixation will also impact photosynthesis. Generally, CO2 and light levels are the primary limiting factors for photosynthesis, depending on the plant's environment.

6.6.2. Limiting Factors of Photosynthesis

Any factor that directly or indirectly affects one of these elements will impact the efficiency of photosynthesis. Consequently, actions affecting stomatal opening and CO2 fixation will also influence photosynthesis. Generally, the availability of CO2 and light will be the primary limiting factors for photosynthesis, depending on the plant's environment.

6.6.3. C3 Plants

Most plants are classified as C3, meaning they use three-carbon molecules to produce sugars (see Calvin cycle). These plants primarily inhabit temperate environments. The rate of CO2 fixation in C3 plants increases linearly with light intensity, up to a point known as light saturation intensity, which represents the maximum CO2 assimilation rate and is depicted as a plateau in relation to maximum sunlight exposure. This relationship is due to light’s crucial role in regulating stomatal opening, necessary for CO2 assimilation. There are two scenarios:

- When light is sufficient, reaching light saturation intensity, CO2 becomes the limiting factor for photosynthesis.
- Conversely, if light is inadequate, it will limit photosynthesis.

It is important to note that the light saturation intensity in C3 plants is generally low, due to the slow carboxylase activity of Rubisco, which hinders significant CO2 assimilation. Therefore, CO2 concentration is typically the main limiting factor for photosynthesis in C3 plants.

6.6.4. Solutions for C4 and CAM Plants

As previously mentioned, stomata are crucial for regulating plant transpiration, which is more important than photosynthesis efficiency. In other words, stomata often adjust to conserve water, sometimes at the expense of photosynthesis. To address these constraints and maintain photosynthetic activity, some plants have evolved specialized mechanisms, such as those found in C4 and CAM plants.

C4 plants are adapted to specific conditions, including saline soils, and can perform photosynthesis more efficiently under high light intensity. CAM plants, on the other hand, are found in arid environments and are typically succulents.

6.6.4.1.Characteristics of C4 and CAM Plants

a) C4 Plants

C4 plants enhance CO2 absorption through an additional reaction in the cytoplasm. They utilize both three-carbon and four-carbon molecules for temporary CO2 storage. In this process, CO2 binds with phosphoenolpyruvate (PEP) to form a four-carbon molecule, oxaloacetate, which is then reduced to malate by NADPH. The malate is converted back to pyruvate and CO2 for use in the Calvin cycle. This adaptation increases the CO2 concentration around Rubisco, reducing its oxygenase activity and thus improving photosynthetic efficiency. C4 plants can effectively perform photosynthesis under high light intensities, with their main limitation being low light intensity rather than CO2 concentration.

b) CAM Plants

CAM (Crassulacean Acid Metabolism) plants are adapted to arid environments where water conservation is crucial. They use a similar additional reaction to C4 plants but differ in their nocturnal CO2 fixation. CAM plants open their stomata at night to capture CO2, which is stored as malate. This CO2 is then utilized during the day for photosynthesis, allowing the stomata to remain closed and minimizing water loss. This adaptation leads to higher energy consumption compared to C4 plants but significantly reduces water loss by restricting stomatal openings to the cooler, more humid night.

6.6.4.2.Differences Between C3, C4, and CAM Plants

- In C3 plants, photosynthesis occurs in the palisade mesophyll cells.
- In C4 plants, photosynthesis involves two types of cells: the outer bundle sheath cells, where the additional CO2 fixation occurs, and the inner bundle sheath cells, where the actual Calvin cycle and CO2 fixation take place. This spatial separation enhances CO2 concentration in the bundle sheath cells.
- CAM plants separate CO2 fixation and the Calvin cycle temporally. They fix CO2 at night and perform the Calvin cycle during the day, which allows them to conserve water by keeping their stomata closed during the day.

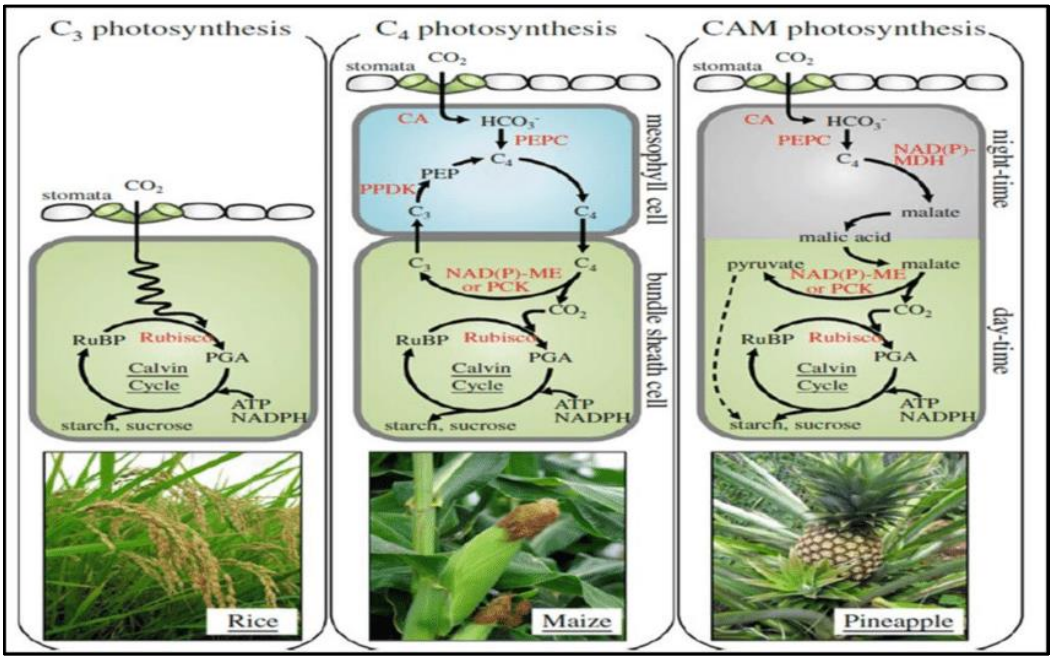

Figure.53. Photosynthesis inC3, C4 and CAM plants

6.6.5. Persistence of C3 Plants

So far, we have observed that C4 and CAM plants offer ingenious solutions to enhance their photosynthetic activity, particularly in challenging environments (hot and dry climates, soils with low water availability, etc.), thanks to their efficient enzyme, PEP carboxylase.

Question: Why haven’t C4 and CAM plants completely replaced C3 plants?

To answer this question, it is crucial to consider the characteristics of Rubisco in relation to temperature fluctuations. Indeed, due to an inherent characteristic of this enzyme and the differential impact of temperature on CO2 and O2 solubility, the ratio of Rubisco's oxygenase activity to its carboxylase activity varies with temperature.

As the temperature rises, the gradient of CO2 concentration decreases, which reduces the enzyme's ability to fix CO2. This effect is particularly pronounced in C3 plants but is less impactful on C4 and CAM plants, which are nearly insensitive to such influences.

At temperatures above 30°C, C4 and CAM plants have a distinct advantage. However, when temperatures drop below 25°C, C3 plants outperform C4 plants, making them more effective in cooler conditions.

Part 2: Development

Part 2 :Development

1. **Seed formation**
2. **Germination**
3. **Growth**
4. **Flowering**
5. **Fructification**

Chapter 1: Seed formation

Chapter 1: Seed formation

Introduction

Seeds develop from the ovary of the flower. Development begins after fertilization of the egg cell by the pollen grain.

1.1. Fertilization

Pollination occurs when wind or insects carry the pollen grain to the stigma of the pistil. Once on the stigma, the pollen grain germinates, forming a pollen tube that grows through the internal tissues of the stigma, style, and ovary to reach the female gametophyte within the ovule. During pollen grain germination, the generative nucleus divides into two sperm nuclei. The elongation of the pollen tube is driven by the vegetative nucleus, which is simply an extension of the inner wall (intine) of the pollen grain. The pollen tube emerges through a pore in the outer wall (exine) of the pollen grain.

It is important to note that the stigma is distant from the ovary. Fertilization is chalazogamic when the pollen tube enters the ovule through the chalaza, whereas it is porogamic if it enters through the micropyle. When the pollen tube reaches the female gametophyte, one of the synergid cells begins to degenerate to facilitate the entry of the pollen tube's tip. Subsequently, the triploid endosperm is formed by the fusion of the nucleus from the most advanced sperm with the polar nuclei of the female gametophyte. The diploid zygote is formed by the fusion of the nucleus from the last sperm with the ovule. This double fertilization is characteristic of angiosperm fertilization. The sporophyte phase begins with the development of the zygote into an embryo.

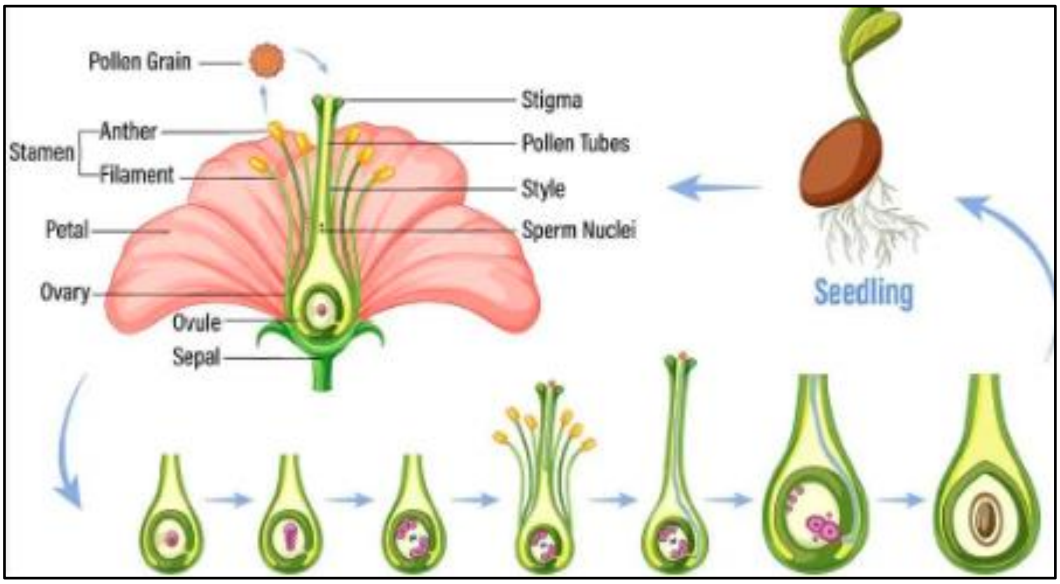

Figure.54. Fertilization.

The seeds are encased by the integument of the ovule, and the endosperm is formed by the fusion of one generative nucleus with the two polar nuclei (triploid cells). The generative nucleus fuses with the ovule to form the zygote, which then develops into the embryo (embryo sac). At this stage, the ovule consists of the embryo sac, surrounded by the nucellus and one or two integuments, all connected to the carpel by the funiculus. Before endosperm formation, there is at least one primary vascular bundle supplying nutrients to the ovule. The outer integument is penetrated by vascular tissue that extends through the funiculus to the chalazal pole.

1.2. Seed parts

The following elements can be identified in a classic seed:

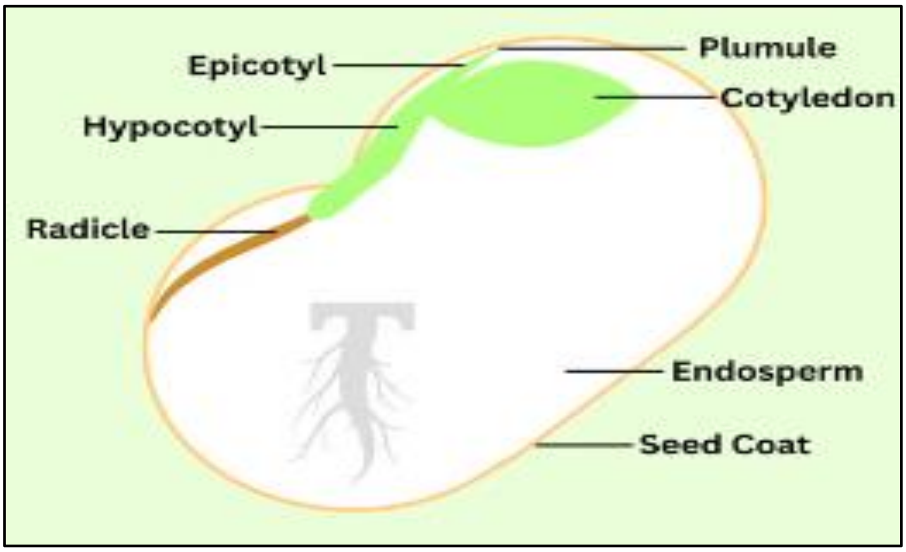

Figure.55. Seed parts

- **Embryo**

The process of embryogenesis progresses from the zygote to the final embryo. During this phase, the apical and basal (shoot-root) and radial (internal-external) axes are established. The initial division of the zygote produces two cells: an apical cell and a basal cell. The embryo develops from the apical cell, while the basal cell forms a suspensor that anchors the embryo at the micropyle region and facilitates nutrient transfer.

Cells derived from the apical cell proliferate to form a proembryo, a rounded mass of cells that expands and grows, marking the beginning of cellular differentiation. The protoderm develops at the periphery, while the interior differentiates into the ground meristem and procambium. As the embryo develops, the activity of the meristems becomes restricted to the extremities of the embryo, the apical meristems.

Before entering dormancy, the mature embryo consists of an epicotyl (above the cotyledons) with an apical meristem and stem primordium, cotyledons, and a hypocotyl (below the cotyledons) with part of the stem primordium and root primordium. The plumule refers to the most developed part of the stem (the epicotyl), while the radicle refers to the embryonic root.

In dicotyledons, the longitudinal wall separates the zygote into two future cotyledons. The cotyledons appear as leaf-like structures attached to the embryo by vascular tissue. When they serve as the primary reserve for germination, they are fleshy. In monocotyledons and some dicotyledons, the cotyledons are absorptive, with nutrients stored mainly in other parts of the seed.

In these cases, the cotyledons temporarily supply nutrients to the embryo. If they are the primary source of energy, they lack meristems but retain some meristematic activity if involved in photosynthesis. During germination, the cotyledons are connected to the embryo by a point called the node and open like a book. Monocotyledons have a similar embryonic development to dicotyledons but persist longer due to the presence of a single cotyledon. The apical meristem in grass embryos consists of leaf primordia forming a protective sheath called the coleoptile and a root with a protective sheath called the coleorhiza.

- **Endosperm**

The endosperm is a nutritive tissue that surrounds or is located adjacent to the embryo. In angiosperms, it forms as a result of the fusion of a sperm nucleus with two polar nuclei, resulting in triploid tissue known as secondary endosperm. In gymnosperms, the endosperm is haploid and referred to as primary endosperm. The endosperm provides nutrients to the embryo and supports the plant during the early stages of growth. It contains starch or proteins, which may form amorphous granules known as gluten or crystalline protein complexes called aleurone grains. The nucellus is an additional storage tissue belonging to the ovule, forming perisperm in some angiosperm species, although it is absent in many seeds.

At maturity, seeds with endosperm are known as endospermic or albuminous seeds. Seeds that consume the endosperm during the early stages of maturation are called non-endospermic or exalbuminous seeds. These seeds accumulate nutrients in the cotyledons, as seen in peas, beans, and mustard.

- **Seed Coats**

Seed coats are the integuments of the ovule, the tissues surrounding it. Before fertilization, the formation of integuments is limited. However, fertilization allows their development. Seeds have distinct integuments from the internal and external ovule layers. The inner integument becomes the tegmen, while the outer develops into the testa. Generally, the tegmen and testa are closely linked and difficult to separate, except in certain seeds like beans. Both layers are collectively referred to as the seed coat or episperm. Typically, the tissue is thin and flexible, while the testa is hard. A thick cuticle formed by epidermal cells on the testa provides protection against water loss and external pathogens while facilitating gas exchange. Defensins are molecules present in the seed coat of some species that can repel or be toxic to herbivores.

Some seeds contain toxic substances as an additional protective measure. The seed coat usually has thick cell walls, with some cells differentiating into sclereids, though chlorenchyma and aerenchyma may also be present. The histological organization of seed coats varies significantly among species. For example, seed coats in Arabidopsis are composed of three inner layers and two outer layers, forming what is called the tegument. The inner layer is the endothelium, while the other two inner layers fuse as the seed grows. The outer layers show significant differentiation and are divided into subepidermal and epidermal layers. The subepidermal layer is very thick, while the epidermal layer includes a mucilaginous layer. In legumes, the seed coat consists of multiple layers with macrosclereids and osteosclereids in the outer layers and parenchyma in the inner layers. In cereals, two cell layers are formed by the endothelium and the outer integument, while the pericarp is partially integument.

Seeds are extremely hard and solid, primarily due to the presence of a large amount of sclereids. However, some are vigorous. In both monocotyledons and dicotyledons, the testa may be ribbed and crested, sometimes with wing-like structures. The function of the seed coats is to protect the seed from the environment while monitoring external conditions to initiate germination when conditions are favorable. Several seed coats have a superficial epidermal layer with a thick cuticle that deters pathogens but promotes gas exchange. The hilum is a scar on the seed coat where the ovule was attached to the funiculus, a small column of cells anchoring the seed to the coat. A micropyle is also present, serving as the entry point for the pollen tube during fertilization and water entry during germination. Functional chloroplasts are present in many seeds, though they may act more as sensors for external environmental variables rather than generating energy.

1.3. Vascularization

Seed Structure

Seeds can vary greatly in size. For instance, orchid seeds are extremely small, with a diameter of about 200 µm, and lack vascular bundles; water and nutrients are therefore diffused via apoplastic pathways (intercellular spaces). In larger and medium-sized seeds, vascular bundles form and are more complex in larger seeds. The vascular network in some seeds ends at the funiculus-ovule junction or at the placenta-chalaza junction. In other seeds, the vascular network extends throughout the seed. Parenchyma cells surround the vascular bundles and are interconnected by numerous plasmodesmata, facilitating the diffusion of molecules transported by the vascular tissue.

1.4.Seed Dispersal

In some seed coats, structures such as spines, wings, or "parachutes" are developed to aid in dispersal by the wind. Animal movements after consuming fruits represent another dispersal mechanism; in these cases, seeds are not digested but are released in the feces.

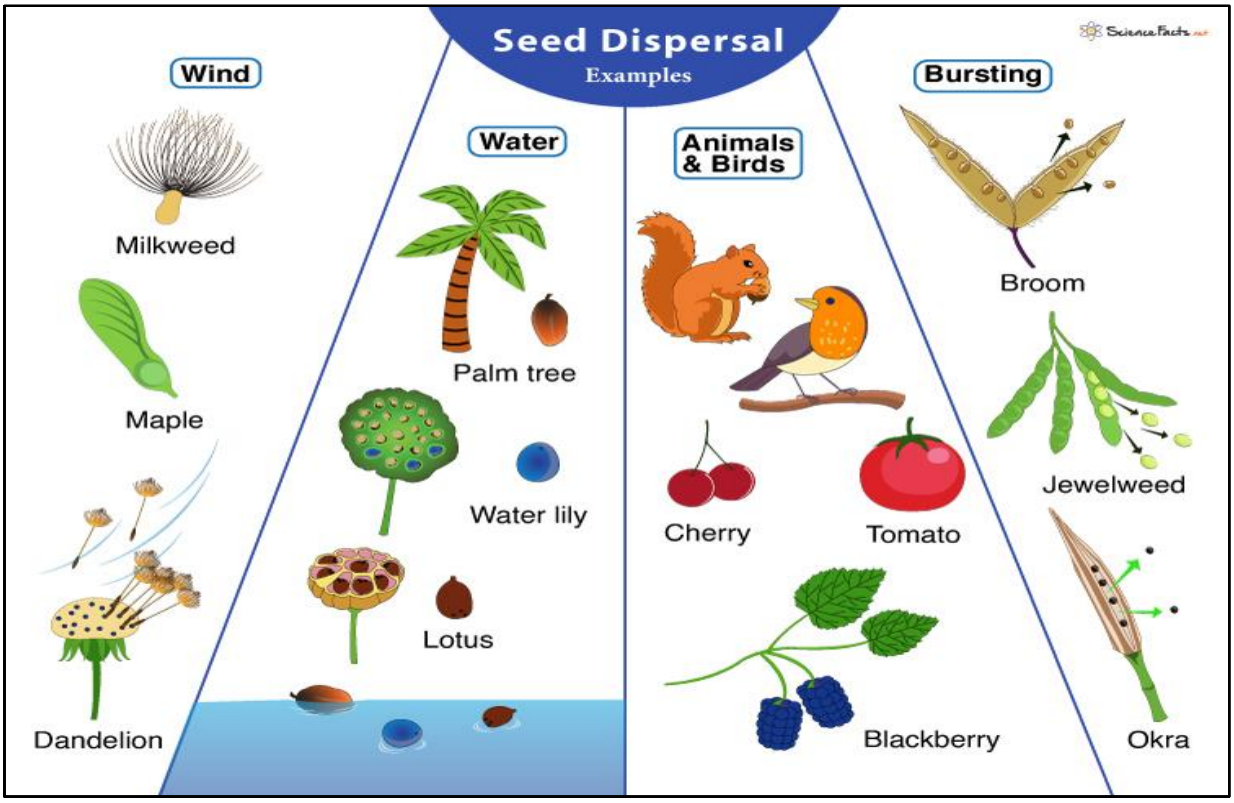

Figure .56. Seed dispersal

1.5. Dormancy

- **Seed Dormancy and Germination**

Seeds represent a significant advancement in terrestrial colonization. What distinguishes seeds is their ability to remain in a dormant state between seed release and germination. Dormancy is a state in which the seed exhibits low metabolic activity or biochemical reactions, minimizing the consumption of energy, oxygen, and water. Dormancy can be broken by a combination of environmental factors such as light, water, temperature, and certain chemicals. These cues signal to the seed that germination will occur in a suitable environment. The seed coat and the cessation of physiological processes in the seed tissues and the embryo determine the state of dormancy.

Dormancy can be ended by the embryo, the endosperm, the seed coat, or a combination of these elements. Unlike animals, plant embryos can remain dormant for extended periods, allowing a cohort of seeds to produce new plants over several years. Remarkably, seeds from soil layers dating back 2,000 years have been germinated and developed into mature plants. Although this is an extreme case, seeds can remain viable for up to 20 years.

Growth inhibitors, primarily abscisic acid, are present in seeds. The seed coat prevents the diffusion of these inhibitors. Conversely, gibberellic acid promotes germination. The end of dormancy is determined by the abscisic acid/gibberellic acid ratio in *Arabidopsis*. Germination is also triggered by other phytohormones, such as auxin, ethylene, and jasmonic acid.

Seeds of a species do not exit dormancy simultaneously. Some seeds remain dormant even under favorable conditions. Notably, some variables that seem unfavorable, such as fire, can trigger the end of dormancy. The "bet-hedging" strategy involves some seeds exiting dormancy in response to favorable conditions, while others remain dormant, waiting for another opportunity. Another approach is to create a population of seeds that differ morphologically and biochemically. Variability in germination timing among seeds with the same genome has been demonstrated. It has been suggested that stochastic processes produce "transcriptional noise" during gene expression.

The goal of these strategies is to stagger the germination of a seed population over time. In this way, a species can generate new plants at different times and in varying environments. Within a single seed population, the abscisic acid/gibberellic acid ratio may vary slightly, leading to different responses. Both the endosperm and the embryo produce abscisic acid, but the endosperm appears to be the main source of abscisic acid for balancing these two hormones. However, the radicle of the embryo determines the end of dormancy.

Question :

Explain the conditions of dormancy in the seed.

Seed dormancy is a crucial adaptive mechanism that allows seeds to delay germination until environmental conditions are favorable. Here’s an explanation of the conditions and mechanisms that regulate seed dormancy:

1. Dormancy Conditions

1. **Environmental Conditions:**
   - **Temperature:** Temperature plays a key role in breaking seed dormancy. Some seeds require exposure to cold temperatures (stratification) or warmth to end dormancy. For example, certain seeds need a cold period to trigger germination, mimicking winter conditions and signaling that it’s time to sprout in spring.

- **Light:** Light is another important factor. Some seeds need exposure to light to germinate, indicating suitable surface conditions. Others may require darkness for germination.
- **Moisture:** Water is essential for germination. Seeds may remain dormant until they are exposed to sufficient moisture, which is necessary for the germination process.

2. **Internal Factors:**

- **Seed Structure:** Dormancy can be caused by a hard or impermeable outer layer that prevents water and gases from entering the seed. Seed coats or fruit structures may protect seeds until conditions are right for germination.
- **Growth Inhibitors:** Seeds often contain chemical substances, such as abscisic acid, that inhibit germination. These inhibitors must be broken down or neutralized before the seed can begin to germinate.

3. **Mechanisms for Breaking Dormancy:**

- **Chemical Reactions:** Seeds may contain germination inhibitors (like abscisic acid) that need to be decomposed or counteracted for germination to occur. Hormones such as gibberellins can counteract these inhibitors and promote germination.
- **Physical Processes:** Environmental factors like fire or passage through an animal's digestive system can alter the seed’s structure, enabling germination.

4. **Adaptive Strategies:**

- **Multiphase Dormancy:** Some seeds exhibit primary and secondary dormancy. Primary dormancy prevents premature germination, while secondary dormancy can occur if initial conditions do not become suitable.
- **Variable Germination Timing:** Seeds of the same species may not all exit dormancy simultaneously. Some seeds may remain dormant even under favorable conditions. This variability can be a strategy to ensure that not all seeds germinate at once, allowing for a spread of germination times and increased chances of successful seedling establishment.

The goal of these strategies is to delay the germination of a population of seeds over time, ensuring that a species can generate new plants at different times and in varying environments. In a single seed population, slight variations in the abscisic acid/gibberellin ratio can lead to different germination responses, with abscisic acid produced by both the endosperm and the embryo, but primarily sourced from the endosperm. The exit from dormancy is ultimately determined by the radicle of the embryo.

Chapitre 2 : Germination

Chapitre 2 : Germination

Introduction

The germination stage is where a dormant seed "wakes up" and begins to grow into a plant. This transition involves complex physiological mechanisms. The process progresses from the initial rehydration of the seed to the emergence of the radicle, marking the beginning of plant growth.

2.1. Types of Seeds

Seeds are categorized based on the structure of their seed coat and endosperm, as well as the presence or absence of certain reserve tissues. Here are the main types:

- **Seeds with Perisperm:** These seeds have a perisperm, which is the remnant of the nucellus that was not digested and serves as a reserve tissue. The perisperm provides nourishment to the developing embryo but is minimally developed in the endosperm.
- **Albuminous Seeds:** These seeds have a thin layer of cotyledons dispersed within the endosperm, which acts as a storage reserve. Examples include the caryopses of cereals like wheat and barley, where the endosperm plays a significant role in nourishing the embryo.
- **Exalbuminous Seeds:** In these seeds, the nucellus is digested by the endosperm, and the remaining reserve materials are stored in the cotyledons. This type includes seeds like peas and beans, where the cotyledons are rich in stored nutrients necessary for seedling development.

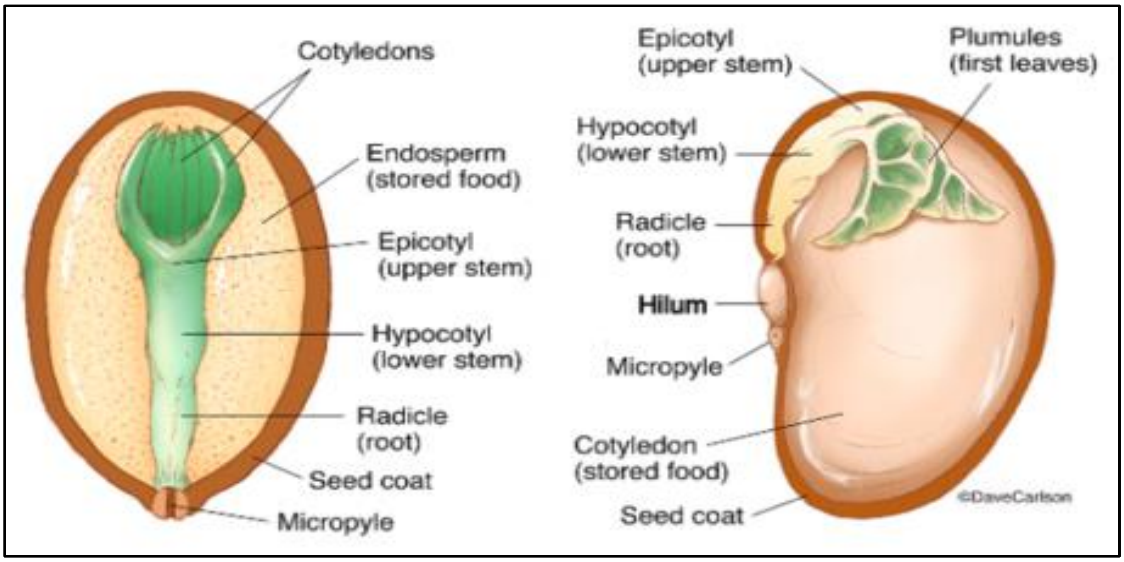

Figure .57.a. perisperm seed, b. albumin seed, c. exalbumin seed

2.2. The stages of germination

Germination can be divided into three successive phases (figure 02): the imbibition phase, the germination phase stricto sensu and the growth phase.

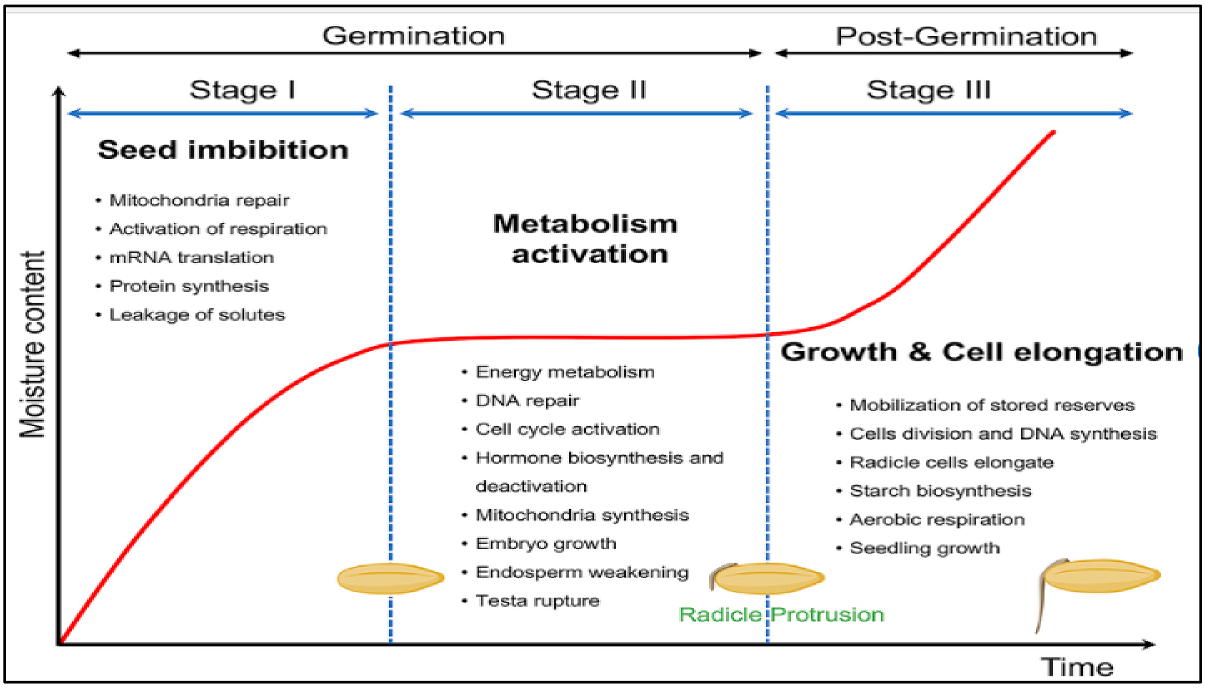

Figure .58. Teoric germination curve

2.2.1. Phase of Imbibition

This phase involves intense hydration of the seed tissues through water absorption, causing the seed to swell. For example:

- Wheat seeds require 47 g of water for every 100 g of seeds.
- Beans require 200 to 400 g of water.

2.2.2. Phase of Germination Sensu Stricto

During this relatively short period (12 to 48 hours), the seed can be repeatedly dehydrated and rehydrated without apparent damage to its viability. This phase ends with the emergence of the radicle through the seed coat.

2.2.3. Phase III

This phase is characterized by increased water absorption and oxygen consumption, representing a growth process that affects the radicle and then the shoot. At this stage, it's important to distinguish between the metabolic activity of the young seedling developing from the embryo, which tends to increase, and the reserve tissues (endosperm, cotyledons), which tend to decrease due to the depletion of reserves.

2.3. Seed Longevity

Seed longevity refers to the length of time a seed can retain its germination capacity under suitable conditions. According to Ewart (1908), seeds are classified into three categories based on their longevity:

- **Macrobioic Seeds:** These seeds have a lifespan of over 15 years.
- **Mesobiotic Seeds:** These are the most common seeds, with a lifespan ranging from 3 to 15 years.
- **Microbiotic Seeds:** These seeds have a lifespan of less than 3 years, with some even dying within a few days or weeks.

2.4. Types of Germination

2.4.1. Epigeal Germination

In epigeal germination, the reserve tissues that constitute most of the seed emerge above the soil. This type of germination primarily involves the considerable elongation of the hypocotyl.

2.4.2. Hypogeal Germination

In hypogeal germination, the reserve tissues that make up the majority of the seed remain below the soil. This type of germination primarily involves the considerable elongation of the epicotyl.

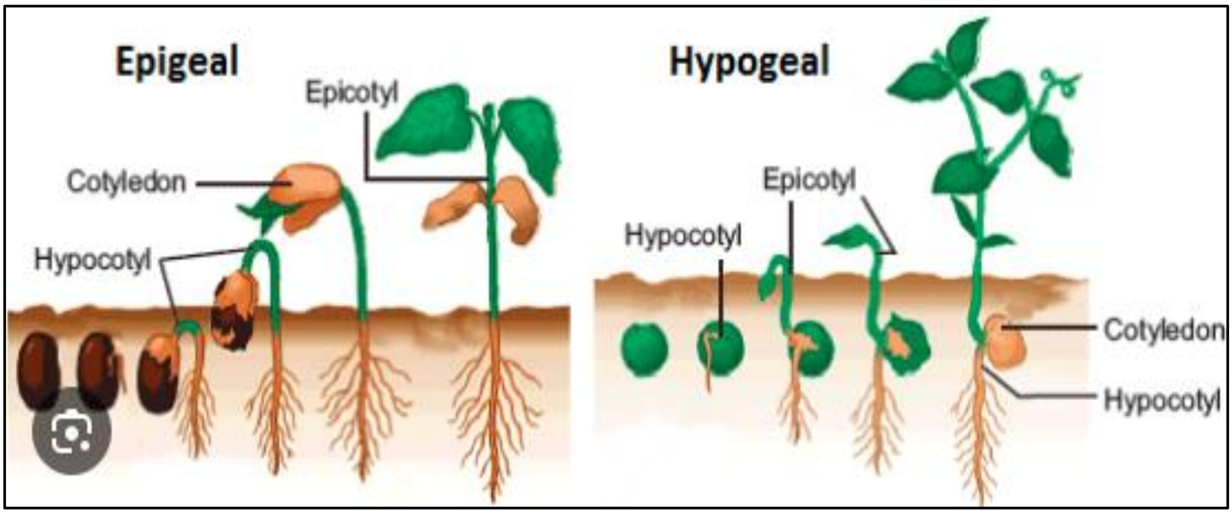

Figure.59. The difference between epigeal and hypogeal germination

2.5. Conditions for Germination

The ability of a seed to germinate can be influenced by various physical and chemical factors in the environment or internal conditions of the seed, depending on its species. Key factors include:

a. Water: Adequate water availability is essential for germination. The seed needs to absorb water from the environment to initiate the germination process.

b. Oxygen: Oxygen is crucial for germination because it supports the respiration processes required for seed growth. Proper aeration of the soil is important to ensure sufficient oxygen availability during seedling emergence.

c. Temperature: Temperature directly affects the rate of biochemical reactions within the seed. Optimal temperatures must be maintained to promote germination, while temperatures that are too low can inhibit the process.

d. Light: The role of light in germination depends on the photosensitivity of the seed species:

- **Positive Photoblasty:** Found in about 70% of seeds, where light is required to initiate germination.
- **Negative Photoblasty:** Rare, observed in some families such as the Liliaceae, where light inhibits germination.
- **Photosensitivity:** Most cultivated plants exhibit some form of photosensitivity, influencing their germination requirements.

e. Maturity: For successful germination, the seed must be fully mature, with all its parts distinct in morphology.

f. Longevity: Seed longevity varies greatly among species. In regions with infrequent favorable conditions for germination, such as arid areas where moisture is not consistently available, seed longevity is of significant biological importance.

Question :

What are the internal and external conditions for germination?

Internal and External Conditions for Germination

Internal Conditions:

1. **Seed Dormancy:** Dormancy is a state where seeds have reduced metabolic activity, which can be broken by specific environmental signals. Seeds need to overcome this dormancy before they can germinate. Internal factors influencing dormancy include:
    - **Seed Coat:** Sometimes, the seed coat is too hard and requires physical or chemical weakening before germination can occur.
    - **Embryo Development:** The embryo must be mature enough to grow. Immature embryos may require a period of maturation before they can germinate.
    - **Internal Inhibitors:** The presence of growth inhibitors such as abscisic acid (ABA) must be reduced. Inhibitors need to be broken down or neutralized for germination to proceed.

2. **Nutrient Reserves:** The seed must have adequate reserves of carbohydrates, proteins, and lipids to support the initial growth of the embryo. These reserves are usually found in the endosperm or cotyledons.
3. **Hormonal Balance:** Internal hormonal signals regulate germination. For example:
   - **Gibberellins:** Promote germination by stimulating enzyme production that breaks down seed reserves.
   - **Abscisic Acid (ABA):** Inhibits germination, and its levels need to decrease for germination to proceed.

External Conditions:

1. **Water (Imbibition):** Water absorption is crucial for activating enzymes that break down stored nutrients and initiate growth processes. Insufficient water can prevent germination.
2. **Oxygen:** Adequate oxygen is necessary for cellular respiration, which provides the energy needed for germination. Compacted or waterlogged soils can reduce oxygen availability and hinder germination.
3. **Temperature:** Seeds have a specific temperature range in which they can germinate. This range varies by species and affects the rate of biochemical reactions in the seed. Extreme temperatures, either too high or too low, can inhibit germination.
4. **Light:** Some seeds require light to germinate, while others need darkness. The type of light sensitivity depends on the seed species:
   - **Photoblastic Seeds:** Require light (positive photoblasty).
   - **Phytochrome Sensitivity:** In some seeds, light quality (such as red or far-red light) influences germination.
5. **pH:** The acidity or alkalinity of the soil affects germination. Most seeds prefer a neutral to slightly acidic pH for optimal germination.
6. **Soil Conditions:** The physical properties of the soil, including texture, structure, and drainage, affect water retention and aeration, impacting seed germination.

Summary:

Germination success depends on a combination of internal factors (like dormancy status, nutrient reserves, and hormonal balance) and external conditions (such as water, oxygen, temperature, light, pH, and soil conditions). Each seed species has specific requirements that must be met for successful germination.

Chapter 3: Growth

Chapter 3: Growth

Introduction

Growth involves a constant increase in all dimensions of the plant: length, width, diameter, surface area, volume, and mass. The development of a plant encompasses two phenomena:

***Increase in Size:** Each organ of the plant enlarges after its initiation.

***Organ Multiplication:** The number of these organs increases, a process known as development.

3.1. Definitions:

3.1.1. Mérèse: This refers to cellular proliferation, characterized by a series of cell divisions or mitoses occurring in specific regions known as meristems. This process leads to the formation of new cells in these meristematic zones, except in leaves where cell division occurs across the entire leaf blade.

3.1.2. Auxèse: This is the process of cellular expansion. It includes:

- **Isodiametric Growth:** Growth where cells expand in all directions equally, regardless of shape (e.g., circular, square, or rectangular), seen in leaf parenchyma, bark, or storage organs.
- **Longitudinal Growth:** Most common, where cells elongate in one direction, increasing the length of the plant.
- **Radial Growth:** Increase in thickness or diameter of plant parts.

3.1.3. **Differentiation:** This process involves cells developing specific morphological features, which vary according to the tissue type, and acquiring new physiological functions, such as those seen in floral development. Differentiation is linked to morphogenesis, which includes:

- **Histogenesis:** Formation of new tissue structures.
- **Organogenesis:** Formation of new organs, including root development (rhizogenesis) and shoot development (caulogenesis).

3.2. Primary Growth:

3.2.1. Primary Meristems: Primary meristems are structures composed of undifferentiated cells with high mitotic activity, responsible for the indefinite length growth of the plant. They emerge during embryogenesis and give rise to primary tissues. Primary meristems are located at the tips of stems and roots. They are small, isodiametric, with a spherical, large nucleus rich in chromatin, numerous tiny vacuoles, and undifferentiated plastids called proplastids.

3.2.2. Shoot Meristem: The shoot meristem produces stems, leaves, axillary buds, and floral buds, making it both histogenic and organogenic. The shoot meristem has three distinct zones:

- **Axial Region:** Produces the epidermis and central tissues of stems and leaves.
- **Lateral Region:** Gives rise to leaves and the medullary meristem that forms the central pith.

3.2.3. Root Meristem: The root meristem develops root tissues and the root cap but is only histogenic, not organogenic. Lateral roots arise from the pericycle at some distance from the root apex and have the same structure and function as the primary root meristem.

3.3. Secondary Growth:

3.3.1. Cambium: Found between the xylem and phloem, the cambium is responsible for producing secondary conductive tissues. It has radial mitotic activity that generates secondary xylem (wood) inwardly and secondary phloem (bark) outwardly.

3.3.2. Phellogen: Located in the bark, the phellogen forms secondary protective tissues, producing cork (suber) externally and phelloderm internally.

This overview highlights the essential processes involved in plant growth and development, from primary growth driven by meristems to secondary growth that increases plant girth and contributes to the formation of various tissues.

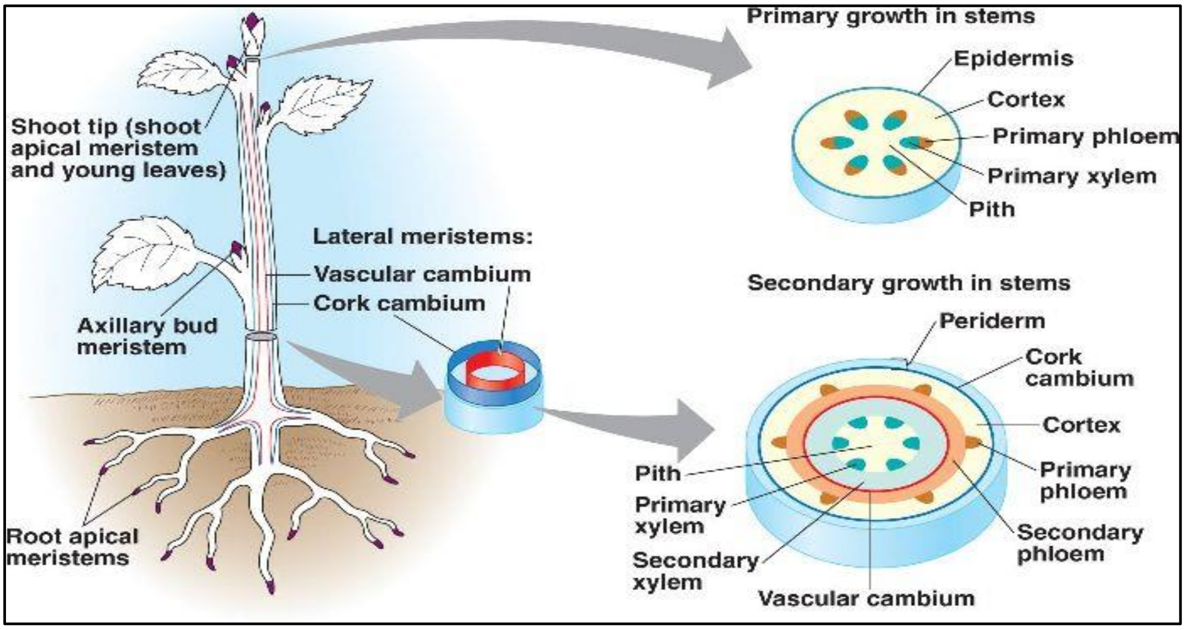

Figure.60. primary growth and secondary growth in plants

3.4. Growth Hormones

Growth hormones are organic compounds produced in one part of the plant and transported to another, where they induce physiological responses at very low concentrations. There are five main groups of natural hormones:

- **Auxins:**
  - Stimulate the growth of coleoptiles and stems.
  - Promote phototropism (growth towards light) and gravitropism (growth in response to gravity).
  - Play a crucial role in the formation of the primary root, lateral roots, and adventitious roots.
  - Zinc and phosphorus deficiencies hinder auxin production.
- **Cytokinins:**
  - Significantly influence seed germination.
  - Encourage cell division and activate the development of leaves and stems.
  - Promote leaf and cotyledon expansion and nutrient transport.
  - Inhibit leaf senescence and help break seed dormancy.
  - Cytokinin production in roots is inhibited by water stress, high temperatures, and hydromorphic conditions.
- **Gibberellins:**
  - Stimulate seed germination, stem elongation, leaf expansion, extended flowering, and fruit growth.
  - Overcome seed dormancy and apical dominance.
  - Prevent leaf dehydration and fruit maturation.
  - Short days and excess water inhibit gibberellin production.
- **Ethylene:**
  - Promotes fruit ripening, leaf senescence, and organ abscission (shedding).
  - Inhibits cell division and elongation of stems and roots.
  - Ethylene production is favored by fruit ripening, leaf and flower senescence, and water stress.
  - Light and anaerobic conditions inhibit ethylene production.
- **Abscisic Acid (ABA):**
  - Inhibits seed germination, axillary bud growth, stem and root elongation, and floral initiation.

- Promotes stomatal closure, leaf senescence, bud dormancy, and tuber and adventitious root formation.
- ABA production increases in response to water stress, excess water, mineral deficiencies, and salinity.

These hormones play crucial roles in regulating various growth processes and responses to environmental conditions.

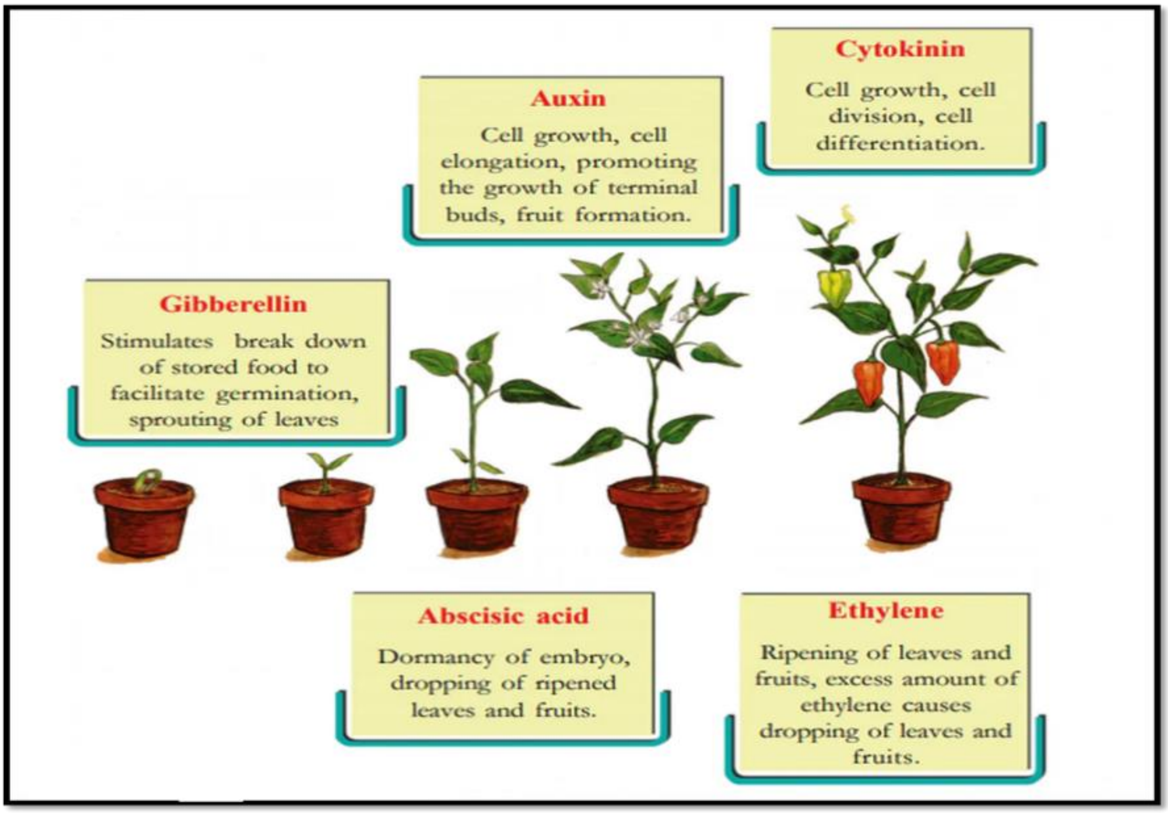

Figure.61. Plant hormones

Question: Explain the role of growth hormones.

Role of Growth Hormones in Plants

Growth hormones, or plant hormones, are crucial for regulating various physiological processes in plants. Each type of hormone plays a specific role in growth, development, and response to environmental stimuli. Here's an overview of the main plant hormones and their functions:

1. **Auxins**
   - **Growth Stimulation:** Auxins promote the elongation of cells in stems and roots, contributing to overall plant growth.
   - **Directional Growth:** They play a key role in phototropism (growth towards light) and gravitropism (growth in response to gravity), helping plants orient themselves properly.

- **Root Formation:** Auxins are essential for the formation of primary roots, lateral roots, and adventitious roots.
- **Tissue Differentiation:** They influence the differentiation of cells into various tissues.
- **Inhibition by Deficiencies:** Low levels of zinc and phosphorus can hinder auxin production and effectiveness.

2. **Cytokinins**

- **Cell Division:** Cytokinins promote cell division and contribute to the development of shoots and leaves.
- **Leaf Expansion:** They enhance the growth of leaves and cotyledons, as well as nutrient transport within the plant.
- **Germination and Dormancy:** Cytokinins facilitate seed germination and help break seed dormancy. They also inhibit leaf senescence (aging).
- **Stress Response:** Water stress, high temperatures, and poor water conditions can inhibit cytokinin production in roots.

3. **Gibberellins**

- **Growth Promotion:** Gibberellins stimulate seed germination, stem elongation, and leaf expansion.
- **Flowering and Fruit Development:** They extend the flowering period and promote fruit growth.
- **Dormancy and Apical Dominance:** Gibberellins overcome seed dormancy and apical dominance (growth inhibition by the main stem).
- **Inhibition by Environmental Conditions:** Short days and excessive water can reduce gibberellin production.

4. **Ethylene**

- **Fruit Ripening:** Ethylene accelerates fruit ripening and the senescence (aging) of leaves and flowers.
- **Abscission:** It promotes the shedding of plant organs, such as leaves and fruits.
- **Inhibition of Growth:** Ethylene can inhibit cell division and elongation of stems and roots.
- **Response to Stress:** Ethylene production is stimulated by stress conditions like water stress and aging, while light and anaerobic conditions can inhibit its production.

5. **Abscisic Acid (ABA)**

- **Growth Inhibition:** ABA inhibits seed germination, growth of axillary buds, and elongation of stems and roots.

- **Stomatal Closure:** It promotes the closure of stomata (pores) to reduce water loss.
- **Dormancy and Stress Response:** ABA enhances leaf senescence, bud dormancy, and the formation of tubers and adventitious roots in response to water stress, excess water, mineral deficiencies, and salinity.

In summary, growth hormones are vital in regulating plant growth, development, and adaptation to environmental changes. They ensure that plants can effectively manage their growth processes and respond to varying conditions.

Chapter 4: Flowering

Chapter 4: Flowering

Introduction

Flowering is a critical factor that influences a plant's life cycle and its ability to reproduce. The vegetative and reproductive phases of a plant's life cycle are determined by the timing of flowering.

4.1. Definition

Flowering refers to the growth of the floral bud, followed by the blooming of the flower or inflorescence, and the production of fruit. The transformation of a leaf bud (shoot apical meristem) into a floral bud (floral meristem) is called floral induction, and it is influenced by various factors such as geographic location, climate, light, temperature, and soil fertility. Plants can be categorized as follows:

- **Annuals:** Flower twice a year (e.g., primrose, cyclamen).
- **Annuals:** Flower once and then die (e.g., marigold, cosmos).
- **Perennials or Multi-annuals:** Flower every year.

4.2. Floral Parts

- **Sepals:** Collectively form the calyx; usually green. These are the outermost parts and protect the flower while it is still in bud.
- **Petals:** Collectively form the corolla; often brightly colored.
- **Androecium:** The collective term for the stamens.
- **Carpels:** The collective term for the gynoecium.
- **Peduncle:** The flower stalk.
- **Bracts:** Modified leaves that can be found at the base of the flower or inflorescence.

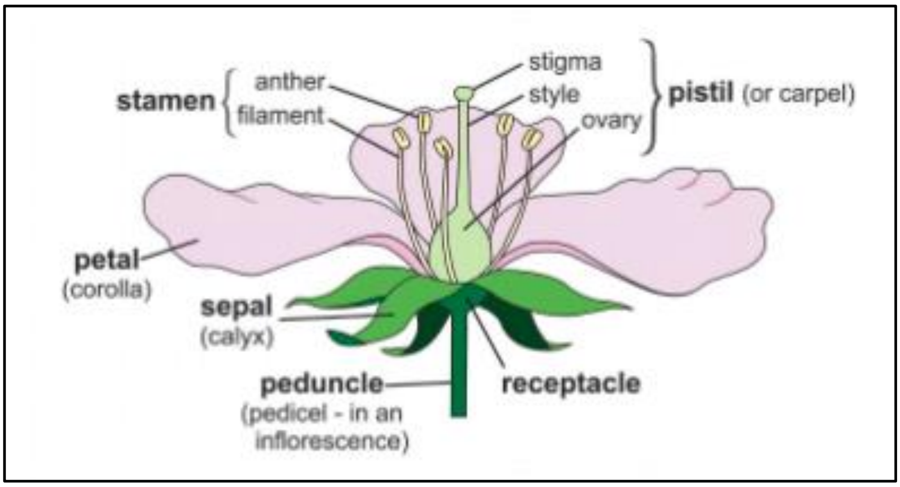

Figure .62. Floral pieces

4.3. Transition from Vegetative to Reproductive State

Flowering represents a critical decision for the plant. The meristem consists of embryonic cells that divide to produce the shoot, leaves, and roots (vegetative meristem), or the flower (reproductive meristem). This transition is irreversible and can affect seed quality if it occurs at the wrong time.

- **Synchronization with Favorable Seasons:** Essential for flowering and seed production (ensuring plant persistence).
- **Conditions for Flowering:** Requires several favorable conditions to be met. If these conditions are not present, flowering may not occur.

4.4. Different Stages of the Transition to Reproductive State

The transition involves a complex process divided into two main phases:

1. **Floral Induction:** The initiation of the process where external stimuli (flowering signals) prompt the meristem to reorganize into a floral meristem.
    - **Floral Stimulation:** External stimuli such as geographic location, seasons, temperature, and light are critical.
    - **Internal Stimuli:** The plant’s vegetative state (age, size) must be appropriate for flowering (e.g., oak trees only flower after 40 years).
2. **Floral Morphogenesis:** This involves the development and growth of flowers.
    - **Introduction to Flowers:** Identification of floral structures.
    - **Flowering Period:** Growth and development of the flowers.

4.5. Visible Changes During Flower Induction

- **Meristem Growth:** The meristem becomes larger, wider, and more rounded. The central region of the meristem becomes inactive while the apical region remains active, containing three layers that form the flower organs.
- **Nutrient Flow:** Increased flow of nutrients (e.g., sucrose) and accelerated energy metabolism support the creation of new organs.
- **Mitotic Activity:** Increased in the three cellular layers of the tunica.
- **Floral Morphogenesis:** The flower develops and grows.

4.6. Floral Initiation

As soon as the vegetative meristem is reorganized into a pre-floral or inflorescence meristem, the process begins. In a floral bud, the inflorescence meristem generates:

- **Floral Parts:** Various floral organs.
- **Final Floral Meristems:** Secured reproductive meristems in floral buds.

4.7. Flowering Process

- **Growth of the Flower:** Includes the development of stamens (male organs), carpels (female organs), gametes, petal coloration, and petal release.

Summary

- **Vegetative Plant:**
  - Floral Induction
  - Floral Evocation
  - Floral Initiation
  - Flowering
- **Flowering Plant:**
  - **IF + EF** = Floral Transition
  - **IF + F** = Floral Morphogenesis

1. Sensitivity to external stimuli.
2. Emission of the flowering signal.
3. Reorganization of the meristem.
4. Classification of floral forms.
5. Formation of floral parts and growth of the flower.

Chapter 5 : Fructification

Chapter 5 : Fructification

Introduction

In botany, the fruit is the plant organ that contains seeds in flowering plants, a characteristic feature of angiosperms.

5.1. Definition

After flowering, the fruit develops from the ovary. It replaces the flower through the transformation of the pistil. The wall of the ovary forms the pericarp of the fruit, while the ovule develops into the seed.

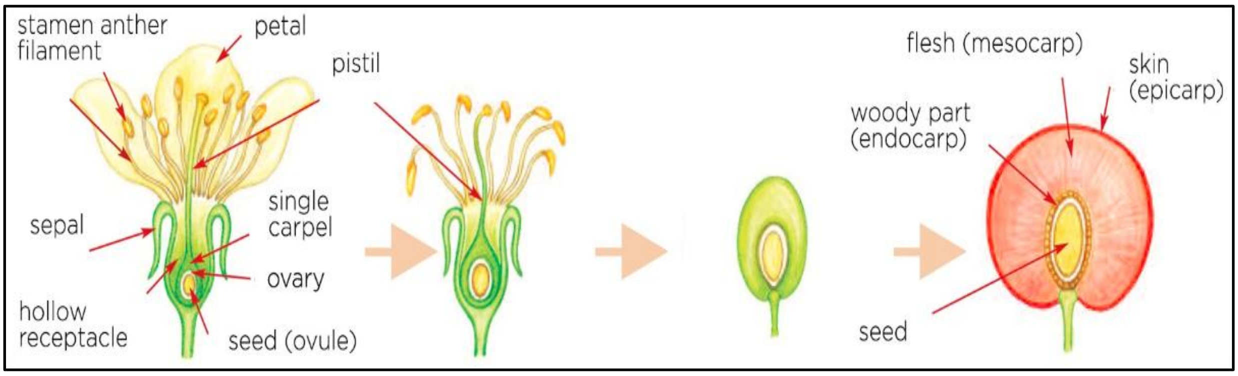

Figure.63. Fruit formation

5.2. Fruit Formation

Generally, the transition from flower to fruit, or "fruit set," is followed by fertilization. Parthenocarpy refers to fruit development without fertilization, resulting in fruits without seeds. Thus, the fruit is the product of the ovary and its contents after fertilization (referred to as a true fruit): the carpels, after fertilization, become seeds, and the flower transforms into a fruit. Pollination is a crucial step in this process. However, some species exhibit parthenocarpy, producing fruits without pollination, resulting in seedless fruits (e.g., bananas, seedless mandarins). Horticulturists are familiar with the development of parthenocarpic fruits and may pursue this trait. Common examples include certain grapefruit varieties, Navel oranges, ordinary bananas, and clementines.

5.3. Types of Fruits

Fruit growth can be either succulent, leading to fleshy fruits such as berries (e.g., grapes, bananas, tomatoes) and drupes (e.g., olives, peaches, cherries), or lignified at maturity in the case of dry fruits. Dry fruits can be dehiscent, meaning they open to release seeds, such as follicles (e.g., peony, magnolia), pods (e.g., peas, beans), and siliques (e.g., cabbage, radish, rapeseed), or indehiscent, such as achenes (e.g., sunflower, buttercup), caryopses (e.g., grasses), and samaras (e.g., maple, ash).

5.3.1. Simple Fruits

Simple fruits are either dry or fleshy and originate from a single ovary within a flower with a single pistil.

5.3.1.1. Fleshy Fruits

Fleshy fruits are characterized by their fleshy texture at maturity, with part or all of the pericarp (fruit wall) being fleshy. The flesh and flavor of the epicarp and mesocarp (and sometimes other parts) are fleshy. The chemical composition of fleshy fruits varies depending on their color and ripeness. In the unripe stage, these fruits contain starch, tannins, and organic acids (such as tartaric, malic, and citric acids). As the fruit matures, this composition changes: starches tend to be replaced by sugars like glucose, lactulose, and sucrose. Chlorophyll disappears, and new pigments, often anthocyanins (e.g., in privet berries) and carotenoids, develop. Fleshy fruits are categorized into two main types: berries and drupes.

- **Berries**: These are a type of fleshy fruit. Examples include grapes, tomatoes, apples, pomegranates, dates, oranges, and bananas.
- **Drupes**: Drupes are stone fruits with a seed called a pit or "endocarp," which is lignified. Examples include olives, plums, peaches, cherries, and coconuts.

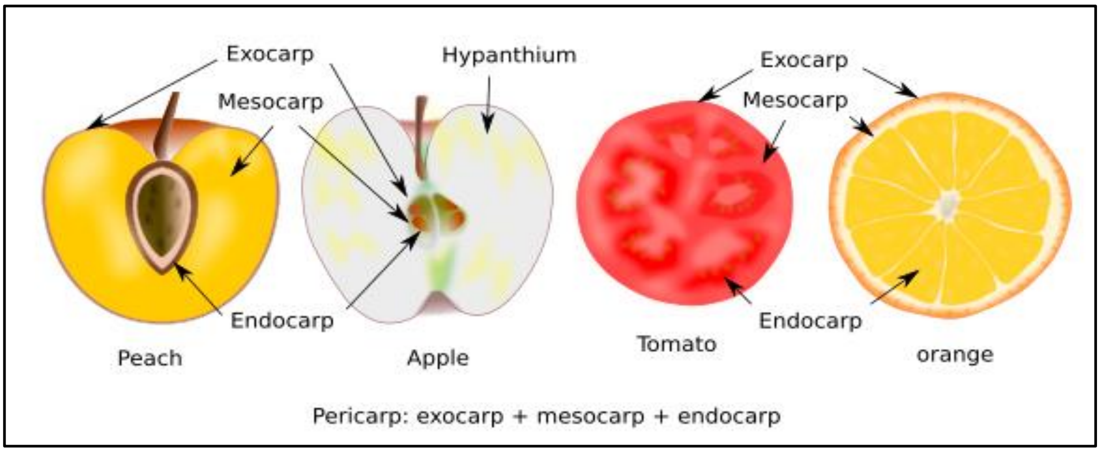

Figure.64. Fleshy fruits

5.3.1.2. Dry Fruits

Dry fruits contain little water (the pericarp is dry), which allows them to be preserved for extended periods. They are classified into two categories:

- **Dehiscent Dry Fruits (Capsuloides)**: These fruits open at maturity through splits or pores, releasing their seeds. Examples include:

  - **Capsules**: Found in plants such as cotton, poppy, and iris.
  - **Follicles**: Examples include peas and lupines.
  - **Pods (Legumes)**: Seen in plants like beans and peas.
  - **Siliques**: Found in cabbage, mustard, and other members of the Brassicaceae family.
- **Indehiscent Dry Fruits (Akenoids)**: These fruits do not open at maturity. The fruit retains the seed inside, and the dry pericarp surrounds a single locule (unilocular ovary) containing just one seed. Examples include:
  - **Achenes**: Such as those found in sunflowers and buttercups.
  - **Samaras**: Winged fruits like those of maples and ashes.
  - **Nuts**: Examples include acorns (oak), beech mast (beech), and chestnuts.

Caryopses

Caryopses are a type of dry fruit characteristic of the Poaceae family, also known as grasses. In a caryopsis, the seed is fused with the fruit wall, meaning that the pericarp (fruit wall) and seed coat are inseparable. This type of fruit is particularly adapted for dispersal and germination in grass species.

Examples:

Corn (Maïs): The caryopsis of corn has the seed adhering tightly to the fruit wall, making it challenging to separate the seed from the fruit.

Wheat: Similar to corn, wheat has a caryopsis where the seed and fruit wall are fused, making the seed an integral part of the grain.

Caryopses are well-suited for the environment and dispersal methods typical of grasses, such as wind or animal-assisted dispersal.

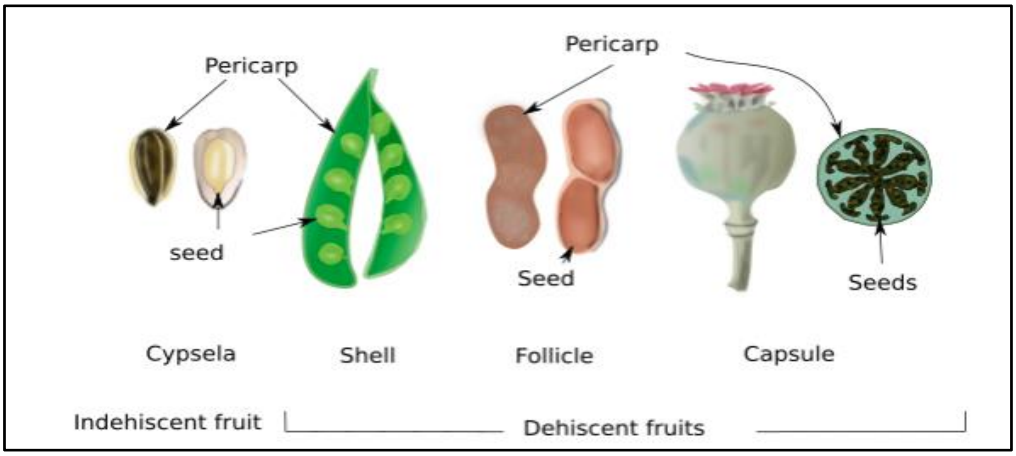

Figure. 65. Fruits secs

Conclusion

Conclusion

The science of plant physiology highlights the great complexity and ingenuity of the mechanisms that govern plant life. Plant growth and development are essential to these processes, which also play a vital role in terrestrial ecosystems and in the regulation of biogeochemical cycles. It is therefore crucial to master plant physiology for practical applications such as sustainable agriculture, natural resource management and the fight against climate change.

The study of plant physiology is essential for preserving biological diversity, improving food production and ensuring the health of ecosystems, highlighting the importance of plants in our daily lives and in maintaining the planet's ecological balance.

Knowledge of plant physiology is essential for preserving biological diversity, improving food production and ensuring the health of ecosystems, highlighting the importance of plants in our daily lives and in maintaining the ecological balance of our planet.

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