1 (a) Define the following briefly (any five):

- (i) Osmosis: Osmosis is the net movement of water molecules across a selectively permeable membrane from a region of higher water potential (lower solute concentration) to a region of lower water potential (higher solute concentration).
- (ii) Aeroponics: Aeroponics is a method of growing plants in an air or mist environment without the use of soil or an aggregate medium. The plant roots are suspended in the air and misted with a nutrient-rich solution.
- (iii) Etiolation: Etiolation is a phenomenon in plants grown in partial or complete absence of light, characterized by long, weak stems, smaller leaves, and a pale yellow color due to a lack of chlorophyll synthesis.
- (iv) Photomorphogenesis: Photomorphogenesis refers to light-mediated plant growth and developmental responses that are independent of photosynthesis. These responses are typically mediated by specific photoreceptors like phytochromes and cryptochromes, influencing processes like germination, de-etiolation, and flowering.
- (v) Bolting effect: Bolting effect is the rapid elongation of the floral stalk (stem) in plants, usually leading to premature flowering, often induced by prolonged exposure to cold temperatures (vernalization) or specific photoperiods.
- (vi) Bioassay: A bioassay is a quantitative or qualitative method for determining the concentration or potency of a substance (e.g., a hormone or toxin) by measuring its effect on living organisms or cells. For example, the Avena curvature test is a bioassay for auxins.

(b) Fill in the blanks (any five):

- (i) The water potential of pure water is **zero** at standard atmospheric pressure and temperature.

- (ii) **Abscisic acid (ABA)** is also called as stress phytohormone.
- (iii) Membrane channels that facilitate transport of water are called **aquaporins**.
- (iv) A cell becomes flaccid after being kept in **hypertonic** solution.
- (v) Gene expressed before FT (full name of FT mention here: **Flowering Locus T**) during flowering is known as **Constans (CO)**.
- (vi) Ordinary companion cells with development of finger-like wall ingrowths are called **transfer cells**.

 (c) Name any five of the following:

- (i) A synthetic antitranspirant: **PMA (Phenylmercuric acetate)** or **ABA (Abscisic Acid)**
- (ii) An ethylene-releasing compound: **Ethephon**
- (iii) Donnan equilibrium: **Frederick George Donnan**
- (iv) Photoreceptor: **Phytochrome** or **Cryptochrome** or **Phototropin**
- (v) Chelating agent: **EDTA (Ethylenediaminetetraacetic acid)**
- (vi) One example of photoblastic seed: **Lettuce** or **Tobacco**

2 Differentiate between the following (any five):

- (i) Passive and active transport
  - **Passive Transport:**
    - Movement of substances across a membrane down their electrochemical potential gradient (from high to low concentration).
    - Does not require direct expenditure of metabolic energy (ATP).
    - Examples: Diffusion, facilitated diffusion, osmosis.

- **Active Transport:**
  - Movement of substances across a membrane against their electrochemical potential gradient (from low to high concentration).
  - Requires direct expenditure of metabolic energy (ATP).
  - Carried out by specific transport proteins (pumps).
  - Examples: Proton pumps, ion channels.

- (ii) Phloem loading and unloading
  - **Phloem Loading:**
    - The process by which sugars (primarily sucrose) produced during photosynthesis are actively transported from source cells (e.g., mesophyll cells in leaves) into the sieve tubes of the phloem.
    - This increases the solute concentration in the sieve tubes, leading to a decrease in water potential and subsequent influx of water.
  - **Phloem Unloading:**
    - The process by which sugars are actively or passively transported out of the sieve tubes at sink tissues (e.g., roots, fruits, growing tips) where they are consumed or stored.
    - This decreases the solute concentration in the sieve tubes, leading to an increase in water potential and subsequent efflux of water.
- (iii) Scarification and stratification
  - **Scarification:**

    - A process that involves breaking, scratching, or weakening the hard, impermeable seed coat to allow water and gases to penetrate, thus promoting germination.
    - Can be physical (e.g., rubbing with sandpaper), chemical (e.g., acid treatment), or mechanical.
  - **Stratification:**
    - A process of subjecting seeds to a period of cold, moist conditions to break dormancy.
    - Mimics natural winter conditions, allowing physiological changes (e.g., degradation of germination inhibitors or synthesis of growth promoters) necessary for germination.
- (iv) Apoplast and symplast
  - **Apoplast:**
    - The continuous system of cell walls, intercellular spaces, and dead xylem vessels in plants, forming a pathway for water and solute movement.
    - Movement is relatively unrestricted and does not involve crossing cell membranes.
    - Important for bulk flow of water in the xylem and initial water uptake by roots.
  - **Symplast:**
    - The continuous network of cytoplasm connected by plasmodesmata (cytoplasmic bridges) between adjacent plant cells.

        - Movement of water and solutes occurs through the cytoplasm, requiring passage across at least one cell membrane (e.g., entering the root hair cell).
        - Important for intercellular communication and transport of nutrients.

- (v) Climacteric and non-climacteric fruits
    - **Climacteric Fruits:**
        - Fruits that continue to ripen after being harvested.
        - Exhibit a characteristic burst of ethylene production and a sharp increase in respiration rate (climacteric rise) during ripening.
        - Examples: Apples, bananas, tomatoes, avocados.
    - **Non-climacteric Fruits:**
        - Fruits that do not continue to ripen significantly after being harvested.
        - Do not show a climacteric rise in ethylene or respiration.
        - Examples: Oranges, grapes, strawberries, cherries.
- (vi) Guttation and transpiration
    - **Guttation:**
        - The exudation of xylem sap (water and some solutes) from the margins or tips of leaves, typically through specialized pores called hydathodes.
        - Occurs under conditions of high humidity and low transpiration, when root pressure is high.
        - The exudate appears as droplets of liquid water.
    - **Transpiration:**

    - The loss of water vapor from the aerial parts of plants, primarily through stomata in the leaves.
    - Driven by the water potential gradient between the leaf interior and the atmosphere.
    - The primary mechanism for water transport through the xylem (transpiration pull) and for cooling the plant.

3 Write short notes on (any three):

- (i) Hydroponics
  - Hydroponics is a method of growing plants without soil, using mineral nutrient solutions dissolved in water. The plant roots are either immersed in the nutrient solution or are exposed to it intermittently.
  - **Key Features:**
    - **Controlled Environment:** Allows precise control over nutrient supply, pH, and oxygen levels to the roots, optimizing plant growth.
    - **No Soil-borne Diseases:** Eliminates issues with soil-borne pests and diseases.
    - **Water Efficiency:** Can be highly water-efficient as water can be recirculated and recycled, reducing wastage.
    - **Space Efficiency:** Can be set up in vertical farms or other confined spaces, maximizing yield per unit area.
    - **Nutrient Delivery:** Nutrients are supplied directly to the roots in readily available forms.
  - **Types:** Include deep water culture, nutrient film technique (NFT), ebb and flow (flood and drain), drip systems, etc.
  - **Applications:** Used for growing vegetables, herbs, and flowers, particularly in areas with poor soil quality, limited

space, or water scarcity. It is also used in research to study plant nutrient requirements.

- (ii) Brassinosteroids
  - Brassinosteroids (BRs) are a class of polyhydroxysteroid phytohormones that play essential roles in various aspects of plant growth and development. They are structurally similar to animal steroid hormones.
  - **Physiological Roles:**
    - **Cell Elongation and Division:** Promote stem and root elongation, and cell division, contributing to overall plant growth.
    - **Vascular Differentiation:** Crucial for the differentiation of xylem and phloem tissues.
    - **Reproduction:** Influence pollen tube growth and seed development.
    - **Stress Tolerance:** Enhance plant tolerance to various abiotic stresses (e.g., drought, cold, salinity, heat) and biotic stresses (e.g., pathogen attacks).
    - **De-etiolation:** Promote light-induced developmental changes, such as leaf expansion and chlorophyll synthesis.
    - **Photomorphogenesis:** Interact with other light signaling pathways.
  - **Mechanism of Action:** BRs are perceived by cell surface receptor kinases (e.g., BRI1), leading to a signal transduction cascade that ultimately regulates gene expression, often through the phosphorylation and dephosphorylation of transcription factors. Their widespread influence makes them important targets for improving crop yield and stress resistance.

- (iii) Cohesion-tension theory
    - The cohesion-tension theory is the widely accepted model that explains the upward movement of water (xylem sap) from the roots to the leaves in tall plants, against the force of gravity. It relies on three key properties of water and plant structures:
    - **1. Transpiration Pull (Tension):** Water evaporates from the stomata on the leaf surface, creating a negative pressure (tension or pull) in the xylem vessels of the leaves. This tension extends throughout the continuous water column in the xylem.
    - **2. Cohesion of Water:** Water molecules are highly cohesive due to hydrogen bonding, meaning they stick strongly to each other. This cohesive force allows the entire water column in the xylem to be pulled upward as a continuous thread, without breaking, from the roots to the leaves.
    - **3. Adhesion of Water to Xylem Walls:** Water molecules also adhere to the hydrophilic inner surfaces of the xylem vessels. This adhesion helps to counteract the force of gravity and prevents the water column from breaking away from the walls.
    - **Continuous Water Column:** The xylem vessels form a continuous network of tubes from the roots to the leaves. As water evaporates from the leaves, the tension generated pulls water molecules from adjacent water molecules below, creating a continuous upward flow. The roots continuously absorb water from the soil, replenishing the water lost by transpiration. This entire process is driven by the energy from the sun (which drives transpiration).
- (iv) Aphid stylet technique
    - The aphid stylet technique is a precise and widely used method to collect pure phloem sap for analysis, providing direct insight into the composition of translocated sugars, amino acids, hormones, and other substances within the plant.

- **Mechanism:**
  - **Aphid's Natural Probes:** Aphids are sap-sucking insects that insert their long, needle-like mouthparts, called stylets, directly into individual sieve tubes of the phloem to feed on the sugary sap.
  - **Severing the Stylet:** Researchers carefully anesthetize the aphid and then use a fine laser beam or a microsurgical blade to sever the aphid's body from its stylet, leaving the stylet still embedded and sealed within the sieve tube.
  - **Exudation of Sap:** Due to the positive turgor pressure within the sieve tube, phloem sap continues to exude from the cut end of the stylet for several hours or even days.
  - **Collection and Analysis:** The exuding sap can be collected as tiny droplets using microcapillary tubes and then analyzed using various biochemical techniques (e.g., chromatography, mass spectrometry) to determine its chemical composition.
- **Advantages:** The technique provides a relatively pure sample of phloem sap, minimizing contamination from other plant tissues. It also allows for sampling from specific sieve tubes and at different locations along the phloem pathway.
- **Applications:** Revolutionized the study of phloem transport, allowing researchers to understand what nutrients are transported, how quickly, and how the plant allocates resources.

4 (a) Write an explanatory note on structure and mode of action of phytochrome.

- **Structure of Phytochrome:**

- Phytochrome is a family of photoreceptor proteins in plants that are sensitive to red (R) and far-red (FR) light. It exists in two interconvertible forms:
  - **Pr (Phytochrome red):** The physiologically inactive form that absorbs red light (peak absorption at ~660 nm).
  - **Pfr (Phytochrome far-red):** The physiologically active form that absorbs far-red light (peak absorption at ~730 nm).
- **Molecular Structure:**
  - Phytochrome is a homodimer, meaning it consists of two identical polypeptide subunits.
  - Each subunit is composed of two main domains:
    - **N-terminal Photoreceptor Domain:** This domain contains a covalently attached linear tetrapyrrole chromophore called **phytochromobilin**. The chromophore is responsible for absorbing light. The absorption of red or far-red light causes a reversible isomerization (conformational change) of this chromophore, which in turn leads to a conformational change in the entire protein.
    - **C-terminal Regulatory/Kinase Domain:** This domain is involved in dimerization of the two subunits and mediates signal transduction. It possesses protein kinase activity or interacts with other signaling molecules.
  - **Interconversion:**
    - When Pr absorbs red light, it is rapidly converted to Pfr.

    - When Pfr absorbs far-red light, or is in darkness for a prolonged period, it is converted back to Pr. Pfr is generally less stable than Pr and undergoes slow degradation in the dark.

- **Mode of Action of Phytochrome:**
  - The physiological activity of phytochrome is primarily attributed to the **Pfr form**. The ratio of Pfr to Pr in the cell determines the plant's response to light.
  - **1. Light Perception and Conformational Change:**
    - Pr absorbs red light and undergoes a conformational change to become Pfr. This change exposes a functional domain or alters its interaction with other proteins.
    - Pfr absorbs far-red light and reverts to Pr.
  - **2. Signal Transduction (Cytoplasmic and Nuclear):**
    - The active Pfr form can initiate signal transduction pathways.
    - **Cytoplasmic Action:** Pfr can physically interact with various cytoplasmic proteins, influencing their activity or localization. For example, Pfr can move from the cytoplasm into the nucleus.
    - **Nuclear Action:** In the nucleus, Pfr directly interacts with and phosphorylates specific transcription factors (e.g., PIFs - Phytochrome Interacting Factors).
    - **Ubiquitination and Proteasomal Degradation:** A key mechanism involves Pfr interacting with and often promoting the ubiquitination and subsequent degradation of transcriptional repressors (e.g., COP1, PIFs) that normally inhibit photomorphogenesis in the dark. By

degrading these repressors, Pfr allows the expression of light-responsive genes.

- **Kinase Activity:** The C-terminal domain of phytochrome can have serine/threonine kinase activity, phosphorylating downstream signaling components.

- **3. Gene Expression Regulation:**
    - The ultimate outcome of phytochrome signaling is the regulation of gene expression. Pfr activation leads to changes in the transcription of hundreds of genes involved in various developmental processes.
    - For example, Pfr promotes the expression of genes for chlorophyll synthesis and leaf expansion (de-etiolation), while repressing genes for stem elongation.
- **Physiological Responses:** Phytochrome regulates a wide range of plant processes, including:
    - Seed germination (e.g., light requirement for lettuce seeds)
    - De-etiolation (greening of seedlings)
    - Flowering (photoperiodism)
    - Shade avoidance syndrome
    - Circadian rhythms
    - Phototropism (though primarily mediated by phototropins)

- In essence, phytochrome acts as a molecular switch, allowing plants to perceive changes in light quality and quantity, and adjust their growth and development accordingly to optimize survival and reproduction in their environment.

 (b) Explain the mechanism of stomatal opening and closing with reference to proton transport theory.

- Stomata are pores on the leaf surface, flanked by two guard cells, that regulate gas exchange (CO_2 uptake) and transpiration. The opening and closing of stomata are primarily regulated by changes in the turgor pressure of the guard cells, which is explained by the **proton transport theory (or K^+ ion pump theory)**.
- **Mechanism of Stomatal Opening (in light):**
  - **1. Blue Light Perception:** When blue light (a component of sunlight) hits the guard cells, it is perceived by photoreceptors (e.g., phototropins) in the guard cell membrane.
  - **2. Proton Pump Activation:** This light signal activates **plasma membrane H^+-ATPases (proton pumps)** in the guard cell membrane. These pumps actively transport protons (H^+) out of the guard cells into the surrounding subsidiary cells and epidermal cells, utilizing ATP as energy.
  - **3. Membrane Hyperpolarization:** The efflux of positive H^+ ions creates an electrochemical potential gradient, making the inside of the guard cell membrane more negative (hyperpolarized).
  - **4. K^+ Influx:** This hyperpolarization drives the passive influx of potassium ions (K^+) from the subsidiary cells into the guard cells through voltage-gated K^+ channels. Chloride ions (Cl^-) also enter the guard cells to maintain charge balance.
  - **5. Organic Acid Synthesis:** Simultaneously, in response to low intracellular CO_2 (due to photosynthesis in guard cell chloroplasts) and proton efflux, malate is synthesized within the guard cells. HCO_3^- (from CO_2 hydration) exchanges with Cl^-, and malate is stored as malate^{2-}.
  - **6. Water Potential Decrease:** The accumulation of K^+ ions, Cl^- ions, and malate within the guard cells significantly increases the solute concentration, thereby lowering the water potential of the guard cells.

  - **7. Water Influx and Turgor Increase:** Water then moves by osmosis from the surrounding epidermal cells (which have a higher water potential) into the guard cells. This influx of water increases the turgor pressure within the guard cells.
  - **8. Stomata Opening:** The guard cells swell and, due to their unique unevenly thickened cell walls (thicker on the inner side near the pore), they bow outwards, causing the stomatal pore to open.

- **Mechanism of Stomatal Closing (in darkness or under stress):**
  - **1. Abscisic Acid (ABA) Signaling:** In response to environmental stresses like drought (water deficit), plants produce the hormone abscisic acid (ABA). ABA is transported to the guard cells. In darkness, the lack of blue light also contributes.
  - **2. Proton Pump Inhibition:** ABA and darkness inhibit the activity of the plasma membrane H^+-ATPases, reducing the outward pumping of protons.
  - **3. Ion Channel Activation:** ABA also activates specific ion channels in the guard cell membrane:
    - **Anion Channels:** Cl^- and malate^{2-} efflux channels are activated, leading to the rapid release of these anions from the guard cells.
    - **K^+ Efflux Channels:** Outward-rectifying K^+ channels are activated, causing a massive efflux of K^+ ions from the guard cells.
  - **4. Water Potential Increase:** The efflux of solutes (K^+, Cl^-, malate) increases the water potential within the guard cells.
  - **5. Water Efflux and Turgor Decrease:** Water moves by osmosis from the guard cells to the surrounding epidermal cells

(which now have a lower water potential). This loss of water causes a decrease in the turgor pressure of the guard cells.

- **6. Stomata Closing:** As the guard cells become flaccid, they lose their bowed shape and move closer together, causing the stomatal pore to close, reducing water loss through transpiration.

- This proton transport theory effectively explains how the rapid movement of ions, driven by proton pumps and ion channels, leads to changes in guard cell turgor and thus regulates stomatal aperture.

5 (a) What is photoperiodism? Discuss three general categories of photoperiodic responses with reference to day length.

- **Photoperiodism:**
  - Photoperiodism is the physiological response of an organism to the relative lengths of day and night (photoperiod). In plants, it is a crucial mechanism that allows them to perceive the time of year and synchronize their growth and development, particularly flowering, with favorable environmental conditions. Although commonly referred to as day length, it is primarily the length of the uninterrupted dark period that is the critical factor for many photoperiodic responses.
- **Three General Categories of Photoperiodic Responses with Reference to Day Length:**
  - **1. Short-Day Plants (SDP):**
    - **Definition:** These plants flower only when the day length is shorter than a critical maximum period, or more accurately, when the night length is longer than a critical minimum period. They are typically plants that flower in late summer, autumn, or winter.
    - **Response to Light/Dark:** They require a long, continuous dark period to flower. If the long dark period is

interrupted by a brief flash of light (even a few minutes), flowering is inhibited. This indicates that darkness is the critical factor, and Pfr (the active form of phytochrome, produced by red light) inhibits flowering in SDPs.

- **Examples:** Chrysanthemum, coffee, soybean, tobacco (Maryland Mammoth variety), Xanthium.

- **2. Long-Day Plants (LDP):**
  - **Definition:** These plants flower only when the day length is longer than a critical minimum period, or more accurately, when the night length is shorter than a critical maximum period. They typically flower in late spring or early summer.
  - **Response to Light/Dark:** They require a short, continuous dark period to flower. If a long dark period (which would normally prevent flowering) is interrupted by a brief flash of light, it can induce flowering. This suggests that the conversion of Pfr to Pr (or the absence of Pfr) during the short dark period promotes flowering. Pfr promotes flowering in LDPs.
  - **Examples:** Spinach, radish, barley, wheat, *Arabidopsis thaliana*.
- **3. Day-Neutral Plants (DNP):**
  - **Definition:** These plants flower regardless of the day length, or more precisely, their flowering is not regulated by photoperiod. They may flower over a wide range of photoperods or respond to other environmental cues (e.g., temperature, age, nutrient status).
  - **Response to Light/Dark:** Their flowering time is not significantly affected by changes in the relative lengths of day and night.

        - **Examples:** Tomato, cucumber, maize, rice, pea.

- Understanding photoperiodism is crucial in agriculture for optimizing crop production and managing plant development.

 (b) Describe the physiological role of auxins in plants with suitable diagram.

- Auxins are a class of plant hormones (phytohormones) that play crucial roles in regulating various aspects of plant growth and development. The most common naturally occurring auxin is Indole-3-acetic acid (IAA).
- **Physiological Roles of Auxins (with diagrammatic representations where applicable):**
    - **1. Cell Elongation and Stem Growth:**
        - Auxins promote cell elongation, particularly in young stems and coleoptiles. They do this by increasing the plasticity of cell walls, allowing them to stretch under turgor pressure. This process involves the "acid growth hypothesis," where auxins activate plasma membrane H+-ATPases, leading to acidification of the cell wall, activating expansin proteins that loosen cell wall components.
        - [**Conceptual Diagram:** Illustrate a cell with an auxin molecule binding to a receptor, leading to H+ pump activation, acidification, cell wall loosening, water uptake, and cell expansion.]
    - **2. Apical Dominance:**
        - Auxins produced by the apical bud (shoot tip) inhibit the growth of lateral (axillary) buds. This phenomenon is called apical dominance. If the apical bud is removed, the lateral buds are released from inhibition and start to grow.

  - [**Conceptual Diagram:** Show a plant with a prominent main stem and inhibited side branches. Indicate the apical bud producing auxin, and then show the effect of decapitation allowing side branches to grow.]

- **3. Root Initiation and Development:**
  - Auxins promote the initiation of adventitious roots (roots forming from non-root tissue, like stems or leaves). This property is widely used in horticulture for vegetative propagation (rooting of cuttings). Auxins also influence primary root elongation (though high concentrations can be inhibitory) and lateral root formation.

- **4. Tropisms (Phototropism and Gravitropism/Geotropism):**
  - **Phototropism:** Auxins migrate to the shaded side of the stem, promoting greater cell elongation on that side, causing the stem to bend towards light.
  - **Gravitropism (Geotropism):** In roots, auxins accumulate on the lower side when horizontally placed. However, root cells are more sensitive to auxin, and high concentrations inhibit root cell elongation, causing the root to bend downwards (positive gravitropism). In stems, high auxin concentrations on the lower side promote growth, causing the stem to bend upwards (negative gravitropism).
  - [**Conceptual Diagram:** Show a stem bending towards light with auxin concentration indicated on the shaded side. Show a root bending downwards with auxin concentration indicated on the lower side, inhibiting growth.]

- **5. Fruit Development and Parthenocarpy:**
  - Auxins produced by developing seeds promote fruit growth. Application of exogenous auxins can induce the

development of fruits without fertilization, a phenomenon called **parthenocarpy** (seedless fruit formation, e.g., in tomatoes, grapes).

- **6. Abscission Prevention:**
  - Auxins prevent the premature abscission (shedding) of leaves and fruits by delaying the formation of the abscission layer. Young leaves and fruits produce auxins that maintain their connection to the plant.
- **7. Vascular Tissue Differentiation:**
  - Auxins play a role in the differentiation of xylem and phloem tissues during plant development and in wound healing.

- Auxins, often in interplay with other hormones, orchestrate many fundamental growth processes, making them central to plant development and horticultural practices.

 (c) Discuss the criteria of essentiality of elements and biological roles of phosphorus and calcium in plants.

- **Criteria of Essentiality of Elements:**
  - For a mineral element to be considered "essential" for plant growth and development, it must meet three specific criteria, as proposed by Arnon and Stout in 1939:
    - **1. Direct Requirement:** The element must be directly involved in the metabolism of the plant. Its absence must cause a direct impact on the plant's growth, development, or reproduction, and not merely by affecting microbial activity in the soil or another element's availability.
    - **2. Irreplaceable:** The element's function cannot be substituted by any other mineral element. If the plant shows a deficiency symptom due to the lack of this

element, supplying another element cannot alleviate that symptom.

- **3. Completion of Life Cycle:** The plant must be unable to complete its full life cycle (from germination to seed set) in the absence of the element. If the element is deficient, the plant will fail to grow, reproduce, or produce viable seeds.

- Based on their concentration requirements, essential elements are broadly classified into:
  - **Macronutrients:** Required in relatively large quantities (>10 mmol kg^{-1} of dry matter). (e.g., C, H, O, N, P, K, Ca, Mg, S)
  - **Micronutrients (Trace Elements):** Required in very small quantities (<10 mmol kg^{-1} of dry matter). (e.g., Fe, Mn, Cu, Zn, B, Mo, Cl, Ni)

- **Biological Roles of Phosphorus (P) in Plants:**
  - Phosphorus is a macronutrient typically absorbed as phosphate ions ($H_2PO_4^-$ or HPO_4^{2-}).
  - **1. Energy Metabolism (ATP and ADP):** P is a fundamental component of adenosine triphosphate (ATP) and adenosine diphosphate (ADP), the primary energy currency of the cell. It is crucial for all energy-requiring processes like photosynthesis, respiration, and active transport.
  - **2. Nucleic Acids (DNA and RNA):** P forms the phosphate backbone of DNA and RNA, which carry genetic information. It is essential for genetic continuity and protein synthesis.
  - **3. Phospholipids:** P is a key component of phospholipids, which form the structural basis of all biological membranes (cell membranes, organelle membranes).

  - **4. Phosphorylation:** P is involved in phosphorylation reactions, a critical regulatory mechanism where phosphate groups are added to proteins, activating or deactivating them (e.g., in signal transduction pathways).
  - **5. Coenzymes:** P is a component of several coenzymes, such as NADP$^+$ and FAD, which are involved in redox reactions in metabolism.
  - **6. Root Development and Flowering:** Adequate phosphorus is vital for healthy root development, early plant growth, and timely flowering and seed formation.
- **Biological Roles of Calcium (Ca) in Plants:**
  - Calcium is a macronutrient absorbed as Ca^{2+} ions. It is relatively immobile in the phloem and primarily moves in the xylem.
  - **1. Cell Wall Structure and Integrity:** Ca is a crucial component of the middle lamella, where it forms calcium pectate, strengthening cell walls and providing structural integrity to tissues. Deficiency leads to distorted, soft tissues.
  - **2. Cell Membrane Stability and Permeability:** Ca plays a vital role in maintaining the structural integrity and selective permeability of cell membranes. It helps regulate the transport of other ions across membranes.
  - **3. Cell Signaling:** Ca^{2+} acts as a critical secondary messenger in various signal transduction pathways, mediating responses to hormones, environmental stresses (e.g., drought, cold), and light.
  - **4. Enzyme Activation:** Ca acts as a cofactor for several enzymes (e.g., α-amylase during germination).

- **5. Mitotic Spindle Formation:** It is essential for the proper formation and functioning of the mitotic spindle during cell division.
- **6. Growth of Meristems:** Ca is crucial for the proper development and function of meristematic tissues (apical meristems of roots and shoots), which are responsible for plant growth. Deficiency often appears in young, growing tissues.