Part 2: Development

I. Formation of the Seed

The seed is a reproductive organ that develops from an ovule, typically after fertilization. Ovules are produced both by angiosperms (flowering plants) and gymnosperms (including conifers). The seed provides a favorable environment for the developing embryo and protects it until germination. The growth of the young seedling is largely determined by the reserve stock contained within the seed and its ability to respond to the external environment.

Double Fertilization in Angiosperms

Angiosperms, or flowering plants, are characterized by a "double fertilization" process. One of the male gametes fuses with the oosphere (female gamete) to form a diploid zygote, which then divides to give rise to the embryo. The fusion of the second male gamete with the two polar nuclei leads to the formation of a triploid reserve tissue known as the endosperm (1n paternal chromosomes + 2n maternal chromosomes). The endosperm fills the ovule cavity and serves as a tissue rich in stored nutrients, which will be used by the developing embryo.

Types of Seeds

A seed consists of a seed coat (simple or double) and a kernel formed by the embryo and reserve tissues, which constitute the endosperm. The essential part of the kernel is the embryo. The embryo includes a radicle, which is extended by a hypocotyl bearing the cotyledons. Based on the presence or absence of endosperm, seeds can be classified into three categories:

Perispermic Seeds: These seeds have a very underdeveloped endosperm, with the perisperm (the part of the nucellus that was not digested and serves as a reserve) surrounding it. The reserve is located in the perisperm.

Albuminous Seeds: The nucellus disappears, and the cotyledons are thin, with a well-developed endosperm serving as the reserve tissue.

Exalbuminous Seeds: The nucellus is digested by the endosperm, which will then be broken down to form the embryo. The cotyledons contain the stored nutrients, as seen in species like peas or beans.

Seed Maturation and Longevity

Seed maturation is generally accompanied by a significant and consistent decrease in water content. This water loss can reach up to 95% of the fresh weight, resulting in the cessation of metabolic activities and the onset of a dormant state (also referred to as "suspended life").

The dehydration process in seeds is initially associated with an intense and temporary synthesis of abscisic acid (ABA), which is recognized as being responsible for establishing dehydration tolerance and seed dormancy during the seed's development on the parent plant.

Longevity of Seeds

Based on the natural lifespan of seeds under typical environmental conditions, they are classified into three categories:

Macrobiontic seeds: These seeds survive for more than 15 years.

Mesobiontic seeds: These seeds remain viable for 3 to 15 years. This category includes the majority of species, with wheat being a prime example.

Microbiontic seeds: These seeds do not survive for more than 3 years. Many of them are sensitive to dehydration. Numerous tropical or subtropical species fall into this category.

Dormancy

Seeds remain in a dormant state—a temporary block of growth and a momentary halt in development—until environmental conditions are ideal for germination. Sometimes, even when placed under optimal germination conditions, seeds do not sprout, which is due to different types of dormancy. The most important types are tegumentary inhibition and embryonic dormancy.

Types of Dormancy

Tegumentary Inhibition

The seed coats surrounding the embryo act as more or less effective barriers to the passage of water or oxygen, and their influence on germination can be significant.

Water Impermeability: Some seeds cannot germinate because their coats do not allow water to pass through. In humid conditions, these seeds do not swell, remain dry, and resist crushing. These seeds are called "hard seeds." Hard-seeded species are commonly found in legumes (e.g., Caesalpinioideae, Mimosoideae, and Papilionoideae).

Oxygen Impermeability: This occurs because the seed coats are poorly permeable to oxygen.

Chemical Inhibitors: The seed coats (or pericarp) often contain inhibitors of germination or growth, such as cyanide, ammonia, ethylene, sulfur derivatives, abscisic acid, and phenolic compounds.

Embryonic Dormancy

Embryonic dormancy originates within the embryo itself, meaning it is not relieved by treatments applied to the seed coats and can manifest even if the embryo is isolated from the seed.

Primary Dormancy: This dormancy sets in during seed maturation and prevents the emergence of the radicle.

Types of embryonic dormancy include:

Photoblastic Dormancy: This dormancy is broken by light.

Scotoblastic Dormancy: This dormancy is broken by darkness.

Xerolablile Dormancy: This dormancy is relieved by prolonged exposure to dry conditions.

Psychrolablile Dormancy: This dormancy is relieved by cold and moist conditions.

Secondary or Induced Dormancy

After dormancy is broken, germination typically proceeds without issues. However, sometimes a secondary dormancy can persist or develop, requiring another dormancy-breaking process. In such cases, dormancy of the epicotyl (or the gemmule) may remain, preventing germination. This secondary dormancy may require additional treatments, such as two successive winters, to be broken before germination can occur.

This type of dormancy is common in certain species that need specific environmental cues (like prolonged cold periods) to resume growth. The presence of secondary dormancy allows the seed to adapt to adverse environmental conditions and ensures that germination occurs only when conditions are truly favorable for survival.

II. Germination

Germination is defined as the events that occur from the dry seed to the emergence of the root (radicle). It begins with water absorption or imbibition, which activates metabolic processes, and ends when the radicle breaks through the seed coat.

Germination requires favorable external conditions—availability of water, oxygen, and optimal temperature—and internal conditions, such as the breaking of dormancy.

The process of germination is divided into three successive phases: imbibition, germination proper, and growth phase. Until the end of the germination proper phase, the seed can be dehydrated without being harmed, but once the radicle begins to grow, dehydration becomes fatal.

Imbibition Phase

Germination begins with the absorption of water by the dry seed. This rapid rehydration, over a few hours, leads to a morphological change expressed by the increase in seed volume. The influx of water activates the seed's metabolism and resumes respiration. The mitochondria in the seed contain functional enzymes that provide enough ATP to support metabolic activities. Additionally, protein synthesis is facilitated by the accumulation of mRNA and the recruitment of ribosomes during the first minutes of imbibition.

Germination Proper Phase

This phase lasts from a few days to several months, depending on the seed's dormancy status. The water content remains relatively stable, with all mechanisms from phase 1 continuing to function. Protein synthesis is activated. This phase prepares the cell growth that will allow elongation of the embryonic axis. DNA repair also takes place during this phase.

Radicle Growth Phase

This phase begins with the emergence of the radicle from the seed coat, marking the completion of the germination process. The radicle then undergoes rapid growth, with an increase in respiratory activity. The water content reaches its peak during the emergence of aerial parts. The metabolic events during this phase primarily involve the breakdown of stored reserves, after which autotrophy gradually establishes itself.

Conditions for Germination

A. Internal Conditions

Maturity: The seed coats and the seed components (albumen and embryo) must be fully differentiated morphologically for the seed to be ready for germination.

Seed Longevity: This refers to the duration for which seeds remain viable and maintain their germination potential.

B. External Conditions

Water: Water is essential for germination and must be in liquid form. Seeds can absorb a small amount of water vapor, but this is generally not enough for germination. Excess water can be harmful, which is why seeds generally do not germinate when fully submerged, except in aquatic plants.

Oxygen: Oxygen is essential for germination, requiring well-aerated soil. The oxygen demand of most seed embryos is low, with 2-5% oxygen typically sufficient for most species.

Temperature: Temperature directly affects the speed of metabolic reactions and can sometimes interfere with oxygen availability. For example, oxygen solubility decreases as temperature increases (as seen in apple trees). Temperate species can germinate at relatively low temperatures, sometimes even around 0°C. In contrast, tropical species require higher temperatures and cannot germinate below 20-25°C. The optimal temperature is the one that allows the fastest germination with the highest germination percentage.

Light: Light can be either favorable or unfavorable for germination. Some seeds exhibit positive photoblastic behavior, meaning they germinate better in light. Others only germinate in the dark, showing negative photoblastism. There are also non-photoblastic seeds, such as many legumes, tomatoes, and squashes, which do not require light for germination.

Two Types of Germination

There are two main types of germination: hypogeous and epigeous.

Hypogeous Germination: In this type of germination, the cotyledons remain in the soil (e.g., peas).

Epigeous Germination: In this type, the cotyledons emerge from the soil (e.g., beans).

The cotyledons serve two successive roles:

Nutritional or Reserve Tissue: The developing plant uses the reserves in the cotyledons to break through the seed coat.

Assimilatory Tissue: Once the cotyledons are above the soil, they are enriched with chlorophyll and function as leaves for photosynthesis.

III. Growth

Strictly speaking, growth is a quantitative phenomenon that refers to the increase in size, mass, and volume. Other qualitative changes, referred to as differentiation, result in the acquisition of new morphological and functional properties. These two sets of changes (quantitative and qualitative) are involved in the broader phenomenon of development or growth.

Mitosis, Auxesis, and Differentiation

Mitosis, or cellular proliferation, occurs in localized regions called primary meristems, which are responsible for growth in length. These meristems are divided into two types:

Apical Meristems: Located at the tips of roots, in the apical buds at the ends of stems and branches.

Axillary Meristems: Located at the axils of leaves.

Secondary meristems, which contribute to growth in thickness, develop in older organs. These are represented by two generative zones:

Vascular Cambium: Responsible for the production of xylem and phloem tissues.

Cork Cambium: Responsible for producing the protective outer layer (periderm), including cork and phelloderm.

Auxesis is most often translated as cell elongation, resulting from the presence of the pecto-cellulosic wall.

Cell differentiation is the process by which cells acquire specific physiological functions, which vary depending on the tissue in which they are located. Differentiation corresponds to the progressive qualitative change of cells towards specialization, leading to the formation of organelles and cellular products.

Rhizogenesis: This process is carried out by the apical meristem located just beneath the root cap. The cells derived from this meristem elongate in the elongation zone, which is located a few centimeters behind the root apex. It is in this zone that the differentiation of tissues takes place.

Caulogenesis: During seed formation, the embryo bears a small stem (hypocotyl) with a rudimentary terminal bud (gemmule), as well as a radicle, responsible for the formation of the root system.

The Stem: The stem is composed of stacked units called phytomers. These units consist of internodes and nodes (where the leaves emerge). An axillary bud is found at the base of each leaf. The organization of the aerial parts of the plant depends on the functioning of the buds. In perennial plants, bud activity continues throughout the plant's life. The apical bud, in particular, opens each spring, ensuring the growth and branching of the stem.

Leaf Formation: Leaves are inserted at the nodes, which contain an axillary bud. It is from this axillary bud that lateral branches develop. The development of the leaves and their corresponding segments mainly occurs in the peripheral zone (PZ) of the bud. This process involves changes in the frequency and polarity of cell divisions.

Factors of Growth: Phytohormones

Phytohormones, or plant hormones, are natural organic substances that influence all physiological processes of growth, differentiation, and development in plants. They also provide plants with the ability to adapt to environmental changes. Phytohormones control and coordinate the appearance, growth, and differentiation of newly formed organs. The two cellular mechanisms responsible for growth are cell division and elongation, both of which are tightly regulated by the combined action of several growth phytohormones, such as auxins, cytokinins, gibberellins, and brassinosteroids.

Other phytohormones, like abscisic acid, jasmonic acid, ethylene, and salicylic acid, are often classified as stress hormones due to their roles in responses to biotic or abiotic stresses. However, these hormones can also be involved in the control of essential developmental stages, such as fruit maturation for ethylene or pollen development for jasmonates.

Overview of Phytohormones

Auxins: Auxins are primarily synthesized in young leaves and are actively transported to other parts of the plant to coordinate growth and facilitate responses to environmental changes.

They promote the elongation of coleoptiles and stems.

Auxins also regulate phototropism (growth towards light) and geotropism (growth in response to gravity).

– Auxins: Auxins play a crucial role in the initiation and formation of the primary root, lateral roots, and adventitious roots. The production of auxins is inhibited by deficiencies in zinc and phosphorus.

Cytokinins: Cytokinins are primarily produced in the roots, from where they migrate to other parts of the plant. They stimulate cell division and growth.

They play an important role in seed germination, stimulate cell division, and activate the initiation of leaves and stems.

Cytokinins promote the extension of leaves and cotyledons, as well as the transport of nutrients.

They also inhibit leaf senescence and help break seed dormancy.

Stress conditions such as water stress, high temperatures, and hydromorphic conditions can inhibit cytokinin production in the roots and their transport to the aerial parts of the plant.

Gibberellins: Gibberellins are involved in several aspects of plant growth:

They induce germination by stimulating the production of enzymes.

They trigger the initiation of flowering.

They promote stem growth (elongation of internodes), shoots, and fruits.

Gibberellins regulate meristem function.

Stress Hormones:

Ethylene:

Ethylene promotes fruit ripening, leaf senescence, and organ abscission.

It inhibits cell division as well as the geotropism of stems and roots.

The production of ethylene is stimulated by fruit ripening, leaf and flower senescence, and water stress. It is inhibited by light and anaerobic conditions. Ethylene synthesis occurs in meristems, young leaves, and embryos.

Abscisic Acid (ABA):

ABA promotes stomatal closure, leaf senescence, bud dormancy, and the formation of tubers and adventitious roots.

It inhibits seed germination, the growth of axillary buds, stem and root elongation, and floral initiation.

Water stress, excess water, mineral deficiencies, and salinity increase the production of abscisic acid.

IV. Flowering

Flowering is the biological process of flower development. It is influenced by both external environmental factors (such as light, humidity, and temperature) and internal factors (such as genetics, phytohormones, and age).

There are different types of flowering plants:

Annuals: These plants bloom, then die within a single year.

Biennials: These plants flower every other year.

Perennials: These plants bloom year after year, typically for several years.

Flower Parts:

Sepals (together called the calyx): These are typically green and serve as the outermost parts of the flower, protecting the bud before it opens.

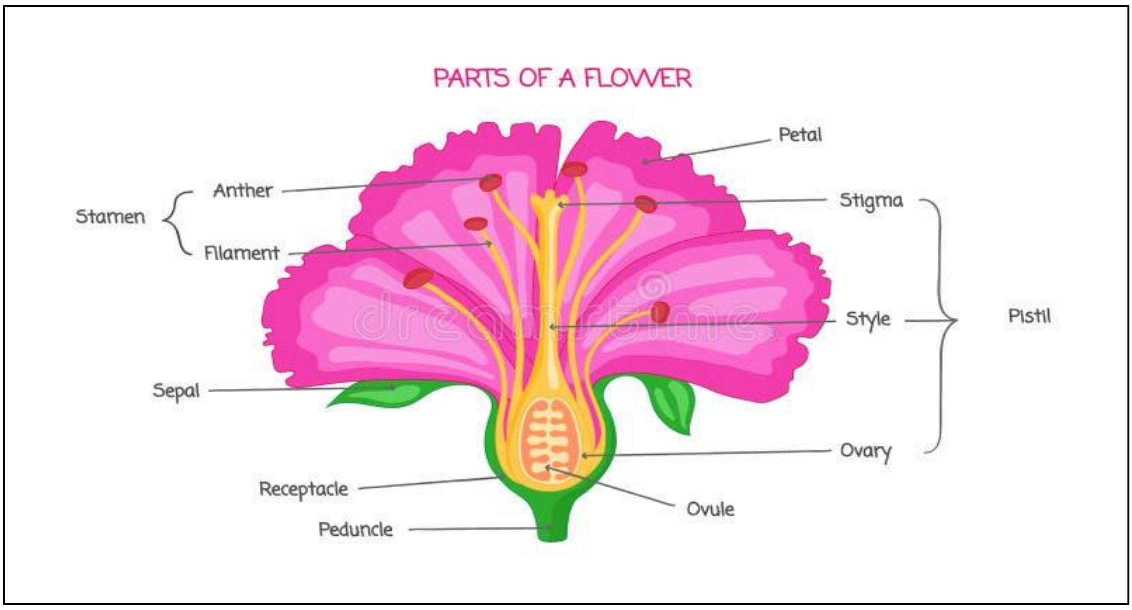
Petals (together called the corolla): These are often brightly colored to attract pollinators.

Stamens (together called the androecium): The male reproductive organs of the flower, which consist of the anther and filament.

Carpels (together called the gynoecium): The female reproductive organs, consisting of the ovary, style, and stigma.

Peduncle: The stem-like structure that connects the flower to the plant, linking it to the main stem or branch.

Bracts: Modified leaves found at the base or in the axils of flowers, often reduced in size or different in color compared to the normal leaves.



Types of Flowers

Hermaphroditic plants: Each flower is bisexual, containing both a pistil (female organ) and stamens (male organs).

Monoecious plants: Male and female organs are located in separate flowers but are borne on the same plant.

Dioecious plants: Male and female organs are located in separate flowers on different plants.

Transition from Vegetative to Floral State

The process of flowering begins with floral induction, which is a preparatory step. During this phase, certain stimuli from the environment trigger the plant's organs to send a signal to the meristem, instructing it to shift from a vegetative development program to a reproductive one.

Floral evocation: This is when the dormant meristem is "awakened," and the architecture of the apical meristem changes. This marks the preparation for the differentiation of floral organs. At this stage, there is an acceleration of the plant's metabolism and an increase in mitotic activity.

Floral initiation: At this point, the primordia (early stages) of the floral parts—both perianth (non-reproductive parts like petals and sepals) and sexual organs (pistil and stamens)—begin to differentiate. In other words, the vegetative bud has now transformed into a floral bud, which causes the bud to swell.

Flowering: The process continues with the development of the floral organs and culminates in the anthesis, which is the full opening of the flowers and the dehiscence (release) of the anthers, marking the completion of flowering.

Factors Affecting Flowering

Flowering is influenced by both internal factors (such as age, size, and maturity) and external factors (environmental conditions), particularly the progression of seasons, temperature, light, and stress. These factors can either promote or inhibit flowering. The two most important external factors are:

Cold Treatment: **Vernalization** Vernalization is the process where exposure to a period of cold temperatures is required to trigger flowering in certain plants. This process helps ensure that flowering occurs only after the plant has experienced a winter period, preventing premature flowering during warm spells. Vernalization is especially important in plants that need a chilling period to transition from a vegetative to a reproductive state.

Light Exposure: **Photoperiodism** Photoperiodism is the response of plants to the length of day and night. Some plants require specific light durations to flower, which can be classified into:

Short-day plants: These plants flower when the night duration exceeds a critical length (e.g., chrysanthemums and poinsettias).

Long-day plants: These plants require a longer duration of daylight to flower (e.g., spinach and clover).

Day-neutral plants: These plants do not depend on the photoperiod and can flower regardless of the light duration (e.g., tomatoes and cucumbers).

The photoperiod influences the production of flowering hormones, particularly in the apical meristem, and helps synchronize flowering with the most favorable environmental conditions.

V. Fructification

Fruits are the result of the transformation of the ovary of a fertilized flower; they contain seeds, which develop from the ovules. The development of the ovary, from its formation within a floral bud to the mature fruit, typically occurs continuously after the flower has been pollinated. However, if the flower is not pollinated, this growth halts abruptly, and the unfertilized flower falls off.

There are, however, some rare exceptions where plants produce fruit without pollination. This phenomenon is known as parthenocarpy, which results in seedless fruits. This can be observed in some species that have been selectively bred and cultivated by humans, such as seedless oranges. Parthenocarpy can occur naturally in some plants or be induced artificially, often through the application of growth regulators or other methods that stimulate fruit development without fertilization.

Types of Fruits

Fruits can develop into either succulent structures, leading to fleshy fruits, or evolve into woody structures at maturity, as in the case of dry fruits.

Fleshy Fruits (Succulent):

These fruits are juicy and tender, typically containing a significant amount of water. Examples include:

Berries: These fruits have a fleshy pericarp and include examples such as grapes, bananas, and tomatoes.

Drupes: These fruits have a single seed surrounded by a fleshy outer layer, such as olives, peaches, and cherries.

Dry Fruits (Lignified):

These fruits become hardened or woody at maturity. Dry fruits can be either **dehiscent** or **indehiscent**:

Dehiscent Fruits: These open up when ripe to release their seeds. Examples include:

Follicles: Found in plants like peonies and magnolias.

Legumes (Pods): Seen in peas, beans, and other leguminous plants.

Silques: Characteristic of plants like cabbage, radishes, and canola.

Indehiscent Fruits: These do not open when mature, and the seeds remain enclosed. Examples include:

Achenes: Seen in sunflowers and buttercups.

Caryopses: Common in grasses, such as wheat and corn.

Samaras: Characteristic of trees like maples and ash, these are winged seeds.

These categories help to distinguish the various types of fruits based on their structure, method of seed release, and how they mature.