1 (a) Give significant contributions of the following (Any two):

- (i) Jensen
    - **William A. Jensen** made significant contributions to our understanding of the ultrastructure and development of the angiosperm embryo sac and embryo, particularly focusing on the processes of fertilization and early embryogenesis using electron microscopy.
- (ii) S.G. Nawaschin
    - **Sergei Gavrilovich Nawaschin** is credited with the independent discovery of double fertilization in angiosperms in 1898, a unique and fundamental process in flowering plant reproduction.
- (iii) P. Maheshwari
    - **Panchanan Maheshwari** was a renowned Indian botanist who made pioneering contributions to plant embryology, particularly in the field of experimental embryology, including the development of techniques for *in vitro* culture of embryos, ovules, and anthers. He also published a classic monograph on "An Introduction to the Embryology of Angiosperms."

(b) Name the species/plant in which the following occurs:

- (a) Largest seed: **Lodoicea maldivica** (Double Coconut or Coco de Mer)
- (b) Pseudo embryo sac: **Podostemaceae** (e.g., *Podostemum*)
- (c) Smallest angiosperm flower: **Wolffia**
- (d) Cleistogamous flowers: **Commelina benghalensis**, **Viola** (Common Pansy), **Oxalis**
- (e) Tristyly: **Lythrum salicaria**, **Oxalis**

(c) Fill in the blanks:

- (i) Pseudomonads are characteristic of family **Onagraceae**.
- (ii) In Litchi, the edible part is **aril**.
- (iii) Ruminate endosperm is found in **Areca catechu** (Areca nut), **Annona squamosa** (Custard Apple), or **Myristica fragrans** (Nutmeg).
- (iv) **Boron** is responsible for crowding effect in pollen germination.
- (v) Reproductive barriers can be overcome by intra-ovarian pollination in members of the family **Papaveraceae**.

2 Differentiate between the following (Any three):

- (i) Homomorphic and Heteromorphic Incompatibility
  - Homomorphic Incompatibility:
    - Definition: A self-incompatibility system where the floral morphology (stamen and pistil length) is uniform within the species. The incompatibility is controlled genetically by a single S-locus with multiple alleles.
    - Recognition: Self-recognition occurs based on molecular interactions between pollen (or pollen tube) and pistil cells, preventing pollen germination or tube growth.
    - Example: Many economically important crops like *Brassica*, *Petunia*.
  - Heteromorphic Incompatibility:
    - Definition: A self-incompatibility system where there are distinct morphological differences (polymorphism) in flower structure within the species, particularly in the length of stamens and styles (e.g., pin and thrum flowers in primroses). Incompatibility is correlated with these morphological types.

    - Recognition: Pollen from a specific anther type can only effectively pollinate a specific stigma type. For example, long-styled (pin) flowers are incompatible with pollen from other pin flowers but compatible with pollen from short-styled (thrum) flowers.
    - Example: **Primula**, **Linum** (flax).

- (ii) Amoeboid and Secretory tapetum
  - Amoeboid Tapetum (or Periplasmodial Tapetum):
    - Cell behavior: The tapetal cells lose their cell walls early in development, their protoplasts fuse, and they form a multinucleate mass (periplasmodium) that invades the sporangial lumen, surrounding and nourishing the developing pollen grains.
    - Breakdown: The entire tapetal layer breaks down and its contents are absorbed by the microspores.
    - Example: Common in monocots like *Typha*, *Tradescantia*.
  - Secretory Tapetum (or Parietal Tapetum):
    - Cell behavior: The tapetal cells remain intact and retain their cell walls throughout microspore development. They secrete nutritive substances and enzymes into the anther locule, which are then absorbed by the developing pollen grains.
    - Breakdown: The tapetal cells eventually degenerate *in situ* after releasing their contents.
    - Example: Most common type in dicots, e.g., *Capsella*, *Gossypium*.
- (iii) Monosporic and Tetrasporic embryo sac development
  - Monosporic Embryo Sac Development:

        - Origin: Only one (usually the chalazal) of the four megaspores formed after meiosis of the megaspore mother cell is functional. The other three degenerate.
        - Divisions: The functional megaspore undergoes three mitotic divisions to form an 8-nucleate, 7-celled embryo sac (e.g., Polygonum type).
        - Ploidy: All nuclei in the embryo sac are haploid (n).
        - Example: **Polygonum type** (most common type in angiosperms), **Oenothera type**.
    - Tetrasporic Embryo Sac Development:
        - Origin: All four megaspore nuclei formed after meiosis remain functional and contribute to the development of the embryo sac. No cytokinesis occurs after meiosis, so a 4-nucleate coenomegaspore is formed.
        - Divisions: The 4 nuclei undergo one or two more mitotic divisions, and then cell walls form to produce the embryo sac.
        - Ploidy: The embryo sac can be 4-, 8-, or 16-nucleate, and some nuclei may be diploid or polyploid if nuclear fusions occur prior to cell wall formation.
        - Example: **Fritillaria type**, **Adoxa type**, **Penaea type**, **Drusa type**.
- (iv) Endothecium and endothelium
    - Endothecium:
        - Location: A specialized layer of cells, usually fibrous, located directly beneath the epidermis of the anther wall.
        - Function: Plays a crucial role in the dehiscence of the anther. It develops characteristic fibrous thickenings

(composed of alpha-cellulose) that create tension upon drying, leading to the splitting open of the anther to release pollen.

- Nature: Part of the anther wall.

- Endothelium:
  - Location: This term is often used to refer to the innermost layer of the integument(s) of an ovule, which sometimes differentiates to form a nutritive layer around the nucellus or embryo sac. It is also sometimes referred to as the integumentary tapetum.
  - Function: Provides nourishment to the developing embryo sac and, later, to the embryo.
  - Nature: Part of the ovule's integuments.

- (v) Ornithophily and Anemophily
  - Ornithophily:
    - Definition: Pollination mediated by birds.
    - Flower characteristics: Flowers are typically large, brightly colored (often red or orange), odorless, and produce abundant, dilute nectar. They often have sturdy structures to provide perching sites for birds.
    - Pollen: Often sticky, and not produced in vast quantities.
    - Examples: **Bignonia**, **Bombax**, **Callistemon**.
  - Anemophily:
    - Definition: Pollination mediated by wind.
    - Flower characteristics: Flowers are typically small, inconspicuous, dull-colored, odorless, and lack nectar and petals. Stamens are often exposed, and stigmas are

large, feathery, or branched to efficiently catch airborne pollen.

- Pollen: Produced in vast quantities, light, dry, and smooth-surfaced, easily carried by wind.
- Examples: **Grasses** (e.g., maize, wheat), **Conifers**, **Oak**.

3 Attempt any two of the following:

- (a) Elaborate upon the significance of reproductive biology in the conservation of plants.
  - Reproductive biology is foundational to plant conservation efforts as it provides critical insights into how plant populations reproduce, maintain genetic diversity, and persist in the face of environmental challenges. Understanding these aspects is crucial for developing effective conservation strategies.
  - **1. Understanding Reproductive Success:**
    - **Pollination Biology:** Knowledge of pollinators (insects, birds, wind, water) and their interactions with plants is vital. If a plant relies on a specific pollinator that is declining, conservation efforts can focus on protecting both the plant and its pollinator. For example, habitat restoration for specific bee species or preventing insecticide use near rare plant populations.
    - **Breeding Systems:** Identifying whether a plant is self-compatible, self-incompatible, outcrossing, or inbreeding helps predict its ability to reproduce and maintain genetic health. Self-incompatible species (e.g., many orchids) require cross-pollination, making them more vulnerable if pollinator populations are low or fragmented.
    - **Seed Set and Viability:** Assessing seed production rates, seed viability (germination success), and dormancy patterns helps determine the reproductive potential of a

population and informs strategies for seed banking or *ex situ* propagation.

- **2. Maintaining Genetic Diversity:**
  - **Gene Flow:** Understanding pollen and seed dispersal mechanisms informs about gene flow between populations. Reduced gene flow due to habitat fragmentation can lead to inbreeding depression and loss of genetic diversity, making populations less resilient to environmental changes or diseases.
  - **Genetic Bottlenecks:** Reproductive biology studies can identify populations that have undergone genetic bottlenecks, guiding strategies for genetic rescue (e.g., controlled crosses, introduction of new genetic material).
  - **Cryopreservation and Seed Banking:** Knowledge of seed dormancy, desiccation tolerance, and germination requirements is paramount for successful long-term seed banking, which serves as a vital *ex situ* conservation tool for genetic diversity.
- **3. *Ex Situ* and *In Situ* Conservation Strategies:**
  - ***Ex Situ* Propagation:** For critically endangered species, understanding their reproductive requirements (e.g., specific germination cues, cloning methods, micropropagation techniques) is essential for successful propagation in botanical gardens or nurseries.
  - **Reintroduction Programs:** Successful reintroduction of plants into their native habitats requires knowledge of their reproductive success in the wild, including factors like seedling establishment, competition, and herbivory.
  - **Habitat Management:** Information on a plant's reproductive needs (e.g., light requirements for

germination, specific soil conditions for seedling establishment, fire regimes for cone opening in some conifers) can guide habitat management practices.

- **4. Addressing Reproductive Barriers:**
  - **Incompatibility:** For species facing reproductive failure due to self-incompatibility or cross-incompatibility, reproductive biology can help identify compatible mates or develop techniques like hand pollination or *in vitro* fertilization.
  - **Hybridization Issues:** Understanding hybridization patterns (natural or anthropogenic) helps in managing populations to avoid undesirable genetic introgression in rare species.
- **5. Predicting Climate Change Impacts:**
  - Changes in temperature and precipitation patterns can affect flowering times, pollinator activity, and seed dispersal. Reproductive biology research can help predict these impacts and guide adaptation strategies.
- In essence, plant conservation without a deep understanding of reproductive biology is like trying to solve a puzzle without knowing the rules. It allows conservationists to move beyond simply protecting land to actively managing populations to ensure their long-term survival and evolutionary potential.

- (b) How is a seed designated as a storage organ? Explain with relevant examples.
  - A seed is indeed designated as a storage organ because it contains significant reserves of food materials that provide the necessary energy and building blocks for the developing embryo during germination and early seedling growth, before

the seedling becomes autotrophic. These food reserves are primarily stored in specific tissues within the seed.

- **Tissues Involved in Storage:**
  - **Endosperm:** In many seeds, the endosperm is the primary storage tissue. It is triploid (3n) and develops from the primary endosperm nucleus after double fertilization. It can be starchy, oily, or proteinaceous.
    - **Examples:**
      - **Cereals (e.g., Wheat, Rice, Maize):** Endosperm is the main storage tissue, predominantly accumulating starch. This is why cereal grains are staple foods globally.
      - **Castor bean (*Ricinus communis*):** Stores abundant oil (lipids) and proteins in its endosperm.
      - **Coconut (*Cocos nucifera*):** The liquid endosperm ("coconut water") and solid endosperm ("coconut meat") are rich in fats and carbohydrates.
  - **Cotyledons:** In many dicotyledonous plants, the endosperm is absorbed during embryo development, and the cotyledons (seed leaves) become greatly enlarged and fleshy, serving as the main storage organs.
    - **Examples:**
      - **Pea (*Pisum sativum*) and Bean (*Phaseolus vulgaris*):** Their large, fleshy cotyledons store proteins and starch.
      - **Peanut (*Arachis hypogaea*):** Stores high amounts of oil and protein in its cotyledons.

        - **Almond (*Prunus dulcis*):** Stores lipids in its cotyledons.

    - **Perisperm:** In some seeds, the nucellus (remnant of the ovule) persists and becomes a storage tissue called perisperm. It is diploid (2n).
      - **Examples:**
        - **Black Pepper (*Piper nigrum*):** Both endosperm and perisperm are present and contribute to food storage.
        - **Beetroot (*Beta vulgaris*):** Perisperm is the main storage tissue.

  - **Types of Stored Food Reserves:**
    - **Carbohydrates:** Primarily starch (e.g., cereals, legumes) provides readily available energy. Hemicelluloses are also stored in cell walls (e.g., date palm seeds).
    - **Lipids (Fats/Oils):** High-energy reserves, particularly common in oilseeds (e.g., castor, groundnut, sunflower, soybean). They yield more energy per unit mass than carbohydrates.
    - **Proteins:** Essential for building new tissues and enzymes (e.g., legumes, castor, cereals). Often stored as aleurone grains.
  - **Significance of Storage:**
    - **Energy for Germination:** The stored food provides the necessary energy for metabolic processes (e.g., respiration) during germination, when the seedling is still underground or before it can perform photosynthesis effectively.

    - **Building Blocks:** The stored proteins, lipids, and carbohydrates provide the raw materials for synthesizing new cells, enzymes, and structural components of the developing seedling.
    - **Early Seedling Establishment:** Adequate food reserves ensure that the seedling can establish itself and grow sufficiently to reach light and develop its own photosynthetic capacity.
    - **Survival in Unfavorable Conditions:** Seeds can remain dormant for long periods, relying on their stored food until environmental conditions (moisture, temperature, light) become favorable for germination.

- (c) Short-distance transport occurs in various embryological tissues. Comment.
  - Short-distance transport, which refers to the movement of substances over relatively small distances (within a few cells or tissues) typically via apoplastic (cell walls and intercellular spaces) or symplastic (plasmodesmata) pathways, is critically important in various embryological tissues for successful reproduction and development in plants. This localized transport ensures precise delivery of nutrients, signals, and regulatory molecules where and when they are needed.
  - **1. Pollen Grain/Pollen Tube and Stigma/Style Interaction:**
    - **Stigma Secretions:** The stigma produces exudates (lipids, carbohydrates, proteins) that are essential for pollen adhesion, hydration, and germination. This is a short-distance secretion from stigma cells to the surface.
    - **Pollen Tube Growth in Style:** The pollen tube grows through the stylar tissue (often a transmitting tissue), absorbing nutrients (sugars, amino acids) from the surrounding cells. This movement of nutrients from stylar

cells to the pollen tube is a short-distance transfer, often involving active transport across the plasma membranes and symplastic/apoplastic movement within the style.

  - **Guidance Cues:** The ovule, funiculus, and synergids produce chemical signals (chemoattractants like defensin-like peptides) that guide the pollen tube towards the micropyle and subsequently into the embryo sac. These signals are transported short distances to establish a concentration gradient.

- **2. Ovule and Embryo Sac Nutrition:**
  - **Nucellus/Integuments to Embryo Sac:** Before and during fertilization, the developing embryo sac relies on nutrients transported from the surrounding nucellus or integumentary cells. These nutrients (sugars, amino acids) move symplastically or apoplastically over short distances into the embryo sac.
  - **Integumentary Tapetum/Endothelium:** In many ovules, the innermost layer of the integument differentiates into a nutritive tissue (integumentary tapetum or endothelium), which acts as a transfer layer, facilitating short-distance nutrient transport to the growing embryo sac.
- **3. Endosperm and Embryo Development:**
  - **Endosperm as a Nurse Tissue:** In endospermic seeds, the endosperm develops first and acts as the primary nurse tissue, synthesizing and storing nutrients. These nutrients are then transported over short distances to the developing embryo.
  - **Embryo-Endosperm Interface:** Specialized cells at the interface between the embryo and the endosperm (e.g., suspensor cells, epidermal cells of cotyledons) are often

highly active in absorbing and processing these nutrients, using transporters to move molecules across membranes.

- **Suspensor Function:** The suspensor in early embryo development is crucial for pushing the embryo into the nutritive endosperm and for absorbing and transferring nutrients from the surrounding endosperm or nucellus to the globular embryo. This is a classic example of short-distance transport between the parent plant/endosperm and the developing embryo.

- **4. Haustoria (Endosperm and Embryo):**
  - Many seeds develop haustorial structures (e.g., endosperm haustoria, suspensor haustoria) that invade surrounding maternal tissues (nucellus, integuments, placenta) to increase the surface area for nutrient absorption. This is a highly specialized form of short-distance transport, maximizing nutrient uptake.
- **5. Perisperm Development:**
  - In perispermic seeds, the nucellus persists and stores food. Nutrients are transported into the developing nucellar cells from the surrounding funiculus and integuments, enabling its role as a storage tissue.
- In summary, short-distance transport mechanisms (involving specific transporters, plasmodesmata, and apoplastic diffusion) are fundamental for establishing nutrient gradients, delivering guidance cues, and nourishing the rapidly developing and highly dependent structures within the ovule and seed, ensuring the successful completion of embryogenesis and seed maturation.

4 Write short notes on the following (Any three):

- (i) Female Germ Unit

- The Female Germ Unit (FGU) is a functional complex within the angiosperm embryo sac that includes the egg cell and its two synergid cells. This unit is critically important for successful fertilization and the initiation of embryogenesis.
- **Components:**
  - **Egg cell:** The female gamete, typically a large, spherical cell with a large nucleus, dense cytoplasm, and few vacuoles. It fuses with one male gamete to form the zygote.
  - **Synergids (2 cells):** Located adjacent to the egg cell at the micropylar end of the embryo sac. They are typically pear-shaped and contain a prominent "filiform apparatus" at their micropylar end.
- **Function:**
  - **Pollen Tube Guidance:** The synergids play a crucial role in attracting and guiding the pollen tube towards the embryo sac, likely by secreting chemoattractants.
  - **Pollen Tube Reception:** One synergid often degenerates just before or upon pollen tube arrival, facilitating the entry of the pollen tube.
  - **Male Gamete Release:** The pollen tube bursts inside the degenerating synergid, releasing the two male gametes.
  - **Nutrient Transfer:** The synergids, with their large surface area and filiform apparatus (a finger-like projection of the cell wall that increases surface area for secretion and absorption), are thought to facilitate the transfer of nutrients from the nucellus to the egg cell and central cell.
  - **Signal Transduction:** The FGU is involved in the complex signaling required for the double fertilization process.

- The FGU acts as a highly specialized system to ensure the precise delivery of male gametes for double fertilization, maximizing reproductive efficiency.

- (ii) NPC system
  - The NPC system refers to the **Nuclear Pore Complex (NPC)**, which is a large, elaborate protein assembly embedded in the nuclear envelope of eukaryotic cells. While not directly an embryological structure *per se*, it is crucial for all eukaryotic cellular processes, including those involved in plant embryogenesis, as it regulates all transport between the nucleus and the cytoplasm.
  - **Structure:** The NPC is a massive complex (over 100 MDa in plants) composed of multiple copies of about 30 different proteins called nucleoporins (Nups). It forms a channel through the double nuclear membrane and has an octagonal symmetry. It consists of cytoplasmic filaments, a cytoplasmic ring, a central framework, a nuclear ring, and a nuclear basket with a distal ring.
  - **Function in a General Cellular Context (and thus in Embryological Tissues):**
    - **Selective Transport:** The primary function of NPCs is to regulate the bidirectional transport of macromolecules (proteins, RNA) between the nucleus and the cytoplasm. Small molecules (ions, metabolites) can diffuse freely, but larger molecules require active transport mechanisms involving specific transport receptors (importins and exportins) and the Ran GTPase cycle.
    - **mRNA Export:** Essential for exporting mature mRNA molecules (encoding proteins needed for development, growth, and metabolism) from the nucleus to the cytoplasm for translation.

        - **tRNA and Ribosomal Subunit Export:** Also facilitates the export of tRNAs and assembled ribosomal subunits (from the nucleolus) to the cytoplasm.
        - **Protein Import:** Imports nuclear proteins (e.g., DNA polymerases, RNA polymerases, transcription factors, histones, ribosomal proteins) synthesized in the cytoplasm back into the nucleus.
        - **Cell Cycle Regulation:** NPCs play a role in regulating the cell cycle by controlling the nuclear localization of cell cycle regulators.
    - In the context of embryology, the proper functioning of the NPC system is fundamental for rapid cell division, differentiation, and gene expression that characterize early embryo and endosperm development, ensuring the precise control of molecular traffic essential for the formation of a new plant.

- (iii) Polyembryony
    - Polyembryony is a phenomenon in which more than one embryo develops from a single ovule or seed. While typically a single zygote develops into a single embryo, polyembryony leads to the formation of multiple embryos.
    - **Types of Polyembryony:**
        - **True Polyembryony:** Multiple embryos arise within the same embryo sac or from different embryo sacs within the same ovule.
            - **Cleavage Polyembryony:** The zygote or young embryo divides into two or more independent units, each developing into a complete embryo. Common in gymnosperms (e.g., Pinus, Cycas) and some angiosperms (e.g., Citrus).

            - **Formation from other cells of the embryo sac:** Embryos can arise from the synergids (nucellar embryos in Citrus), antipodal cells (rare), or the unfertilized egg (parthenogenesis).

        - **False Polyembryony:** Multiple embryos arise from different ovules within the same ovary, or from more than one embryo sac in the same ovule, but each embryo is formed from a separate event (e.g., separate fertilized eggs). This is less common.

        - **Adventive Embryony (Apomictic Polyembryony):** Embryos arise directly from diploid somatic cells of the ovule (e.g., nucellus or integuments) without fertilization or meiosis. These embryos are genetically identical to the maternal parent. This is a common form of polyembryony in many fruit crops.

            - Example: **Citrus**, **Mango**.

    - **Significance:**

        - **Genetic Uniformity:** Adventive polyembryony produces genetically identical offspring, which is advantageous in horticulture for maintaining desired traits and for producing true-to-type plants.

        - **Vigor:** Nucellar embryos often show more vigor than zygotic embryos.

        - **Plant Breeding:** Can be a useful tool in plant breeding programs.

        - **Evolutionary Implications:** Provides insights into the flexibility of reproductive pathways in plants.

- (iv) Endosperm haustoria

- Endosperm haustoria are specialized extensions or outgrowths of the endosperm tissue that penetrate surrounding maternal tissues of the ovule (such as the nucellus or integuments) to absorb nutrients. They represent a significant adaptation for efficient nutrient acquisition by the developing endosperm, which in turn nourishes the growing embryo.
- **Formation and Function:**
  - Haustoria can develop from the chalazal end, micropylar end, or both ends of the endosperm.
  - They are typically highly invasive, often with increased surface area (e.g., branched, papillate) and dense cytoplasm, indicating active metabolic and absorptive functions.
  - They secrete enzymes to break down maternal tissues and then absorb the liberated nutrients, transporting them to the main body of the endosperm.
- **Types/Examples:**
  - **Micropylar Haustorium:** Develops towards the micropyle, often interacting with the degenerating synergids and nucellus.
    - Example: *Lagenaria*, *Argemone*.
  - **Chalazal Haustorium:** Develops towards the chalazal end, penetrating the nucellus and sometimes the integuments.
    - Example: *Hyacinthus*, *Phyllis*.
  - **Other types:** Some plants may have lateral haustoria or more complex branched systems.
- **Significance:**

- **Efficient Nutrient Transfer:** Ensures that the developing endosperm receives a robust supply of nutrients from the parent plant, maximizing the resources available for the subsequent development of the embryo.
- **Competition for Resources:** In some cases, endosperm haustoria can be quite aggressive, competing effectively for nutrients with other tissues in the ovule.
- **Evolutionary Adaptation:** The development of endosperm haustoria represents an evolutionary adaptation to optimize nutrient uptake, contributing to the successful development of a viable seed.

5 Draw well-labelled diagrams of the following (any three):

- (i) T.S. of a mature anther
- (ii) Bitegmic, anatropous ovule with Fritillaria type embryo sac
- (iii) Steps involved in the entry of pollen tube in the embryo sac
- (iv) Ultrastructure of Egg Cell

6 (a) Trace the development of a typical dicot embryo and elaborate on embryo patterning. (8)

- The development of a typical dicot embryo (e.g., in *Capsella bursa-pastoris*, shepherd's purse) is a highly ordered and predictable process that begins with the fertilized zygote and progresses through several distinct stages, establishing the basic body plan and tissue organization of the future plant. This process is often referred to as embryo patterning.
- **Stages of Dicot Embryo Development:**
    - **1. Zygote:** The diploid zygote, formed by the fusion of the egg cell and one male gamete, is initially polarized. It undergoes its first transverse mitotic division, unequal, giving rise to two cells:

    - **Apical (Terminal) Cell:** The smaller cell towards the micropylar end, which will develop into the embryo proper.
    - **Basal Cell:** The larger cell towards the micropylar end, which mostly forms the suspensor.
- **2. Proembryo Stage (1-cell to 8-cell stage):**
    - The apical cell divides longitudinally, then transversely, forming a globular mass of cells.
    - The basal cell typically divides to form a filament of cells called the **suspensor**. The uppermost cell of the suspensor, adjacent to the proembryo, often swells to form the **hypophysis**, which contributes to the root cap and quiescent center. The suspensor anchors the embryo to the endosperm/nucellus and aids in nutrient transport.

- **3. Globular Stage:**
    - The proembryo continues to divide, forming a spherical structure. At this stage, the embryonic cells are undifferentiated, but initial radial patterning (protoderm, ground meristem, procambium) begins to be established.
- **4. Heart-shaped Stage:**
    - Differential growth of the two future cotyledonary primordia gives the embryo a bilobed, heart-like appearance. The shoot apical meristem (SAM) forms in the notch between the cotyledons. The radial pattern becomes more defined.
- **5. Torpedo Stage:**
    - The cotyledons elongate and the embryo becomes elongated, resembling a torpedo. The primary axis

(hypocotyl-radicle axis) elongates, and the distinct vascular tissue (procambium) becomes more apparent.

- **6. Cotyledonary (Mature) Stage:**
    - The cotyledons continue to grow, often bending within the ovule due to limited space. The embryo is fully differentiated, possessing a well-developed radicle (embryonic root) with a root cap, a hypocotyl, an epicotyl (stem region above cotyledons), plumule (embryonic shoot) containing the shoot apical meristem, and the cotyledons. The embryo is now ready for dormancy within the mature seed.

- **Embryo Patterning (Establishment of Body Plan):**
    - Embryo patterning refers to the establishment of the major axes and tissue layers of the plant body during embryogenesis. It's a precise process of cell division, differentiation, and spatial organization.
    - **1. Apical-Basal Axis:** This is the primary axis of the plant, extending from the shoot apex (apical pole) to the root tip (basal pole).
        - Established very early, often by the first unequal division of the zygote. The apical cell gives rise to the shoot and cotyledons, while the basal cell and suspensor contribute to the root pole (hypophysis contributes to root cap and quiescent center) and the suspensor itself.
        - Mutations affecting this axis (e.g., *gnom* in *Arabidopsis*) lead to embryos lacking distinct shoot and root ends.
    - **2. Radial Axis:** This axis determines the concentric arrangement of tissue layers:

- **Protoderm:** The outermost layer, which develops into the epidermis (protective outer covering). It is formed early, often during the globular stage.
- **Ground Meristem:** The middle layer, which develops into the ground tissue system (cortex and pith in stem, cortex in root) responsible for storage, photosynthesis, and support.
- **Procambium:** The innermost cylinder of cells, which develops into the vascular tissue system (xylem and phloem) for long-distance transport.
- This radial patterning is established progressively from the globular to the heart-shaped stage.

- **3. Cotyledonary Patterning:**
  - The development of the two cotyledons (in dicots) defines the specific organization of the embryonic shoot. The shoot apical meristem (SAM) forms between these two primordial leaves.

- **Role of Hormones and Gene Expression:**
  - Embryo patterning is tightly regulated by a complex interplay of phytohormones (especially auxins, cytokinins) and precise patterns of gene expression. Auxin gradients, for instance, are critical for establishing apical-basal polarity and for initiating organogenesis.
  - **Key Genes:** Specific genes (e.g., *WUSCHEL*, *SHOOTMERISTEMLESS* for SAM development; *PIN* genes for auxin transport; *SCR*, *SHR* for root radial patterning) play critical roles in defining cell fates and establishing these patterns.

- In essence, embryo patterning is the blueprint for the entire plant, laying down the fundamental architecture that will guide post-embryonic growth and development.

 (b) What is a Male Germ Unit, and why is it important in double fertilization?

- A **Male Germ Unit (MGU)** is a functional complex in flowering plants that consists of the two male gametes (sperm cells) and the vegetative nucleus (or generative nucleus in some cases) of the pollen grain, all intimately associated with each other. This physical association ensures their coordinated delivery to the embryo sac.
- **Components of the Male Germ Unit:**
  - **Two Male Gametes (Sperm Cells):** These are the actual reproductive cells, usually amoeboid or highly elongated in shape.
  - **Vegetative Nucleus:** The nucleus of the vegetative cell of the pollen grain. Although not directly involved in fertilization, it plays a crucial role in pollen tube growth and guidance.
- **Importance in Double Fertilization:**
  - **1. Coordinated Delivery of Gametes:** The most critical importance of the MGU lies in ensuring the synchronized and efficient delivery of both male gametes to their respective targets within the embryo sac. In many species, the two sperm cells are physically linked to each other and to the vegetative nucleus. As the pollen tube grows, this entire unit moves as a single entity.
  - **2. Double Fertilization (Unique to Angiosperms):** Double fertilization is the hallmark of angiosperm reproduction, involving two distinct fusion events:

    - **Syngamy (Fertilization 1):** One male gamete fuses with the egg cell to form the diploid zygote (2n), which will develop into the embryo.
    - **Triple Fusion (Fertilization 2):** The other male gamete fuses with the diploid central cell nucleus (or polar nuclei) to form the triploid primary endosperm nucleus (3n), which will develop into the endosperm (nutritive tissue for the embryo).
- **3. Efficiency and Precision:** The MGU ensures that both fertilization events occur almost simultaneously and accurately. If the male gametes were delivered individually or haphazardly, the probability of both fusions occurring successfully would be significantly reduced, impacting reproductive success.
- **4. Vegetative Nucleus Role:** While not directly fusing, the vegetative nucleus remains associated with the sperm cells, often preceding them down the pollen tube. It is thought to provide guidance signals or metabolic support for pollen tube growth, ensuring the male gametes reach the embryo sac. Its degeneration upon reaching the embryo sac is also a controlled event.
- **5. Prevention of Non-functional Gametes:** By ensuring both male gametes participate in a productive fusion event, the MGU maximizes the reproductive potential of each pollen grain.