ANGIOSPERM LIFE CYCLE

KEY POINTS

• Double fertilization results in seed with embryo and nutrient source
• Seed(s) enclosed in fruit for protection and dispersal.
• Flowers & fruit attract pollinators, dispersers

I. Development of embryo sac: The female gametophyte

• Embryo sac = female gametophyte
• Develops within an ovule, itself enclosed by ovary at base of carpel.

Development of embryo sac: The female gametophyte

• Within ovule is megasporangium containing diploid megasporocyte
• Divides by meiosis yielding four cells
• Only one survives, the megaspore
Development of embryo sac:  
The female gametophyte

- Three mitotic divisions of megaspore form **embryo sac**
  - a multicellular gametophyte with 8 haploid nuclei (in 7 cells) derived from the 3 mitotic division

Development of embryo sac:  
The female gametophyte

- At one end of sac are the egg plus two synergid cells
- At the other end are 3 antipodal cells
- The large central cell has two polar nuclei

Development of the pollen grain:  
The male gametophyte

- Sporophyte flower produces microspores in anther that form male gametophytes; these are pollen grains, each with 2 haploid cells.
Development of the pollen grain:
The male gametophyte

- Develop within microsporangia (pollen sacs) of anthers.
- Each pollen sac laden with diploid microsporocytes.
- 4 haploid microspores from meiosis.

Development of the pollen grain:
The male gametophyte

- Each microspore undergoes mitosis producing immature male gametophyte with generative cell and tube cell.
- Generative cell divides to form 2 sperm, now mature gametophyte

Pollination

- Pollen carried to sticky stigma of carpel by:
  - most often animal-aided by various attractants (smell, color, shape) and nectar reward: biotic
Pollination

- Pollen carried to sticky stigma of carpel by:
  - biotic
  - Wind: abiotic

Pollination

- Self pollination reduced
  - Differential maturation of stamens and carpels
  - Morphological constraints
  - Dioecy
  - Self-incompatibility

Fertilization and Seed Development

- Pollen grain germinates pollen tube
Fertilization and Seed Development

• Pollen grain germinates pollen tube
• Ruptures through integument of ovule, discharges 2 sperm cells into embryo sac (gymnosperms also discharge 2 but one disintegrates)

Fertilization and Seed Development

• Double fertilization:
  • One sperm unites with egg yielding 2n zygote
  • Other sperm unites with 2 polar nuclei in central cell yielding 3n nucleus.
• WHY WOULD THIS HAPPEN?

Fertilization and Seed Development

• Ovule matures into seed, which is sporophyte embryo with rudimentary root and 1 or 2 seed leaves (cotyledons)
• 3n nucleate cell multiplies into starch-rich endosperm tissue
Fertilization and Seed Development

- Seed now a mature ovule consisting of **embryo**, **endosperm**, **seed coat** derived from **integument**.
- Dehydrated & often dormant; water 5-15% weight.
- Thus, 3 generations contribute to seed

Seeds/Embryo

- Protective seed coat formed from integuments of the ovule.
- Embryonic axis: radicle (embryonic root), hypocotyl, cotyledon, epicotyl.
- Nutritive tissue in endosperm or cotyledons or both.

Seeds/Embryo

- **Dicots**:
  - 2 cotyledons
  - Hypocotyl breaks surface, protects cotyledon
- **Monocots**:
  - 1 cotyledon
  - Coleoptile breaks surface, protects cotyledon
Fruit

• While seeds develop from ovules, fruit forms from thickened wall of ovary after fertilization
• Fruit development accompanies embryo development
• Protects enclosed seed and aids in dispersal

Types of Fruit

• Simple fruits from single ovary
  – Pea = pea pod is fruit encasing seeds (mature ovules)
  – Peach = fleshy and woody pericarp encasing single seed (eat the pulp)
Types of Fruit

- **Simple fruits** from single ovary
  - Pea = pea pod is fruit encasing seeds (mature ovules)
  - Peach = fleshy and woody pericarp encasing single seed
  - Walnut = same! (eat the seed)
  - Apple = incorporates some floral parts (sepals), and receptacle along with ovary

Types of Fruit

- **Aggregate fruits** develop from several carpels that were part of the same flower
Types of Fruit

- **Multiple fruit** develop from several separate flowers e.g. pineapple.

Fruit ripening

- **Dry fruit**: Aging and drying out of fruit tissues
- **Fleshy fruit**: Convert acid organics and starch molecules to sugar, color change often signals ripeness
- Why? What role does the fruit play?

Fruit Dispersal

- Key innovation in angiosperms.
- Fruit eaten by animals, seeds pass through gut and deposited.
  - Some tightly co-evolved
  - Some fruits are relics
- Fruits as burrs attached to hair or feathers.
- Modified sails (wind dispersal) or floats (water dispersal)
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Germination

- **Seed dormancy** provides maximum life of seed for proper germination conditions:
  - sufficient soil dampness
  - appropriate temperature (warm or cold, season)
  - light (shallow burial)
  - in some: enzymes from animal gut
  - in some: smoke, fire

Germination

- Germination usually triggered by water absorption (after above)
  - causes hydration and enzyme activity that starts utilization of stored nutrients of endosperm;
- First structure to emerge: radicle or embryonic root; followed by shoot

Asexual reproduction

- **Vegetative reproduction**: cloning genetically identical individuals
Asexual reproduction

- **Fragmentation** - separation of parent plant into parts that develop into individual plants, starting with adventitious roots off of stem.
  - Function of indeterminate growth of plant tissues
  - Some plants achieve incredible ages via this process
  - E.g. desert creosote

Asexual reproduction

- **Apomixis**: seeds produced without fertilization, via diploid cell in ovule, which gives rise to embryo then mature seed
- dandelions, added advantage of windblown dispersal

Do NOT confuse this with self-fertilization
PLANT TISSUES AND GROWTH

Key Point
- Plant organization is similar to animal:
- Cells → tissues → organ systems → whole plant.
- BUT growth is different (indeterminate), from perpetual embryonic regions (meristems).

Lecture Outline
I. Plant Cells
II. Tissue Systems
III. Growth (General)
IV. Primary Growth: Roots
V. Primary Growth: Shoots
VI. Secondary Growth

Plant Cell
- Review from 190: Generalized plant cell
  - Mitochondria and chloroplasts as organelles
  - Large central vacuole
  - Cell wall
  - Connected by plasmodesmata
Plant Cell

- Plant tissue and growth is based on a division of labor between 5 different types:
  - Parenchyma
  - Collenchyma
  - Sclerenchyma
  - Water-conducting cells: tracheids & vessel elements
  - Food-conducting cells: sieve-tube members

I. Plant Cells

Parenchyma Cells

- least specialized, often no secondary wall, primary wall thin, flexible
- protoplast has large vacuole
- carry out metabolism, synthesis and storage
- photosynthesis in leaf parenchyma cells
- developing cells begin with basic parenchyma-like structure, then specialize

Forms the cortex and pith of stems, the cortex of roots, the mesophyll of leaves, the pulp of fruits, and the endosperm of seeds.
- Living cells and may remain meristematic at maturity (capable of cell division).
I. Plant Cells

**Collenchyma Cells**

- Also lack secondary walls, but thicker primary wall.
- Help support young plants without restraining growth (no lignin).

![Collenchyma cells (in Heliantus stem) (LM)](image)

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**Sclerenchyma Cells**

- Also function in support, but secondary walls lignified, more rigid.
- Cannot elongate, occur where plant has stopped growing in length.
- May be dead at functional maturity.
  - fibers - occur in bundles (flax, hemp)
  - sclereids - shorter, irregular shape, form durable layers (nut shells)

![Sclerenchyma cells in jean (LM)](image)

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**Tracheids and Vessel Elements**
- Water conducting - xylem
- Dead at maturity, but produce secondary walls before protoplast dies, deposited unevenly in rings.
- Tracheids
  - Long, thin, spindle-shaped cells with pits, for water flow; also function in support (secondary wall lignified)
  - Hold water against gravity via adhesion when transpiration is not occurring.
- Vessel elements

![Tracheids and Vessel Elements](image)
Tracheids and Vessel Elements - water conducting cells

- Water conducting - xylem
- Dead at maturity, but produce secondary walls before protoplast dies, deposited unevenly in rings
- Tracheids
- Vessel elements
  - More efficient, angiosperms only*
  - Wider & shorter than tracheids
  - Linked end to end forming tubes
  - May or may not have perforated end walls
  - Pits present for lateral movement of water
  - Most effective when transpiration is occurring.

*S: Convergent/homoplasious in Gnetales and some mosses

I. Plant Cells
Sieve-tube Members - food conducting cells

- Food conducting cells - **phloem**
- Alive at maturity
- In angiosperms, end walls have porous sieve plates; other vascular plants have pores over entire sieve cell
- Companion cells provide nucleus, ribosomes, which are absent from adjacent sieve cells

I. Plant Cells
Sieve-tube Members - food conducting cells

- Note that **phloem** moves liquids bidirectionally!
- Why?
- What goes on in the spring?
- Why doesn't xylem?
- How does this work if sugar flows via a diffusion gradient?

Tree in spring:

Tree in summer:
II. Tissue Systems

Plant Tissue Systems

- These different cell types are arranged during development into sheets of cells with common function
- These tissues are continuous throughout the plant body

A. Dermal (epidermal) - outer tissue
B. Vascular tissue - xylem and phloem (aggregates of cell types)
C. Ground tissue - bulk of young plant, photosynthetic, support, storage.
  - Primarily parenchyma, some collenchyma and sclerenchyma.

III. Growth: General

Growth (General)

- Indeterminate: perpetual embryonic tissue: meristem
- Growth not limited to juvenile or growing stage
- Some plant organs have determinate growth: flowers, leaves, thorns
Primary Growth

- Primary growth in **apical meristems**
- Root tips & shoot buds
- Primary growth is therefore length

III. Growth: General

Secondary Growth

- Secondary growth in **lateral meristems** (vascular cambium and cork cambium)
- Thickening of plant by replacing epidermis with thicker dermal tissue secondary growth
- Vascular tissue also added (wood is secondary xylem)
Growth

• Thus, primary and secondary growth may occur at the same time but at different locations.
• Primary at stems & roots, secondary in older parts of stems & roots (leaves always primary).

III. Growth: General

Growth

• Indeterminate growth does not mean immortality:
• *Annuals* - Grow from seed each year: wildflowers, many grasses.
• *Biennials* - Grow from seed in first year, flower & fruit in second; certain crop plants.
• *Perennials* - Persist through multiple years: trees, shrubs (some very long lived e.g. bristlecone pine).

III. Growth: General

Primary Growth: Roots

• Zone of cell division
• Zone of cell elongation
• Zone of cell differentiation
• Eventually three primary meristems yield:
  – Protoderm ➔ dermal tissue (epidermis)
  – Procambium ➔ vascular tissue
  – Ground meristem ➔ ground tissue
Primary Growth: Roots

- **Zone of cell division**
  - Root cap protects apical meristem.
  - Divides into primary meristems and replaces root cap cells.
  - Quiescent center acts as reserve.

Primary Growth: Roots

- **Zone of cell elongation**
  - Cells elongate > 10x in length pushing root tip ahead
  - Meristem continually adds cells to end (proximal) zone, as the meristem moves further away, cell specialization occurs in...

Primary Growth: Roots

- **Zone of cell differentiation**
  - Tissue differentiation completed
Primary Growth: Roots

- **Root Procambium**
- Forms central **vascular cylinder**, stele
- Dicots: xylem cells radiate in spokes, phloem in between
- Monocots: xylem & phloem develop around central pith of parenchyma cells
- Lateral roots may form from pericycle layer of stele
Primary Growth: Roots

- **Root Procambium**
  - Forms central vascular cylinder, stele
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Primary Growth: Shoots

- Growth in **apical meristems**
- Dividing cells at shoot tip.
- Differentiation into **protoderm, procambium, ground meristem**; produce same tissues as in roots, but arranged differently

Primary Growth: Shoots

- Differs from roots primarily in vascular tissue is peripheral rather than deep
- no central stele, but strands of vascular bundles
  - rings in dicots,
  - scattered in monocots
Primary Growth: Shoots

- With adjacent axillary buds, branching arises without having to develop deep within shoot

Primary Growth: Shoots

- Tissue organization of leaf (remember this is a shoot)
- Upper ground tissue: palisade mesophyll; photosynthesis prominent
- Lower ground tissue: spongy mesophyll: gas exchange prominent
- Why?

Secondary Growth

- Adds girth.
- All gymnosperms, most dicots, rare in monocots.
Secondary Growth

• Two lateral meristems:
  - **Procambium** → vascular cambium
  - **Ground meristem** → cork cambium
    - **Periderm**
    - **Bark**

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VI. Secondary Growth

Secondary Growth

• Two lateral meristems:
  - **Procambium** → vascular cambium → secondary xylem (inside vascular cambium), phloem (outside vascular cambium)
  - **Ground meristem** → cork cambium
    - **Periderm**
    - **Bark**

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VI. Secondary Growth

Secondary Growth

• Two lateral meristems:
  - **Procambium** → vascular cambium
  - **Ground meristem** → cork cambium → cork (tough, replaces epidermis of primary plant body)
    - **Periderm**
    - **Bark**
VI. Secondary Growth

Secondary Growth

- Two lateral meristems:
  - Procambium → vascular cambium
  - Ground meristem → cork cambium
- Periderm: cork cambium + cork
- Bark: all tissue external to vascular cambium (phloem + periderm)

These structures permit growth of plants into canopy to compete for light.

But how do they get nutrients around?

TRANSPORT IN PLANTS

Key Points

- Plants have separation of resource acquisition: shoots (light, CO₂), roots (water, nutrients)
- Transport thus critical: cellular, extracellular, translocation, transpiration.
Relevant Structures

- What structures transport **WATER and soil nutrients**?
- Are these alive or dead?
- What structures transport products of photosynthesis?
- Are these alive or dead?
- Both of these interface with the environment in the leaf.

Leaf structure

- Epidermis of tight, compact cells with external cuticle
- Epidermis broken by pores, or stomata, flanked by guard cells
  - all water evaporation/gas exchange takes place through stomata.
- Ground tissue, the mesophyll, consists of palisade (upper) and spongy (lower) parenchyma.
- Vascular tissue continuous with xylem & phloem of stem

Transport - Overview

**Two keys**

1. **Water** will move from areas of high water potential to areas of low water potential (especially important for xylem).
2. **Solute**s diffuse from areas of high concentration to areas of low concentration (especially important for phloem).

- Both of these result in **equilibration**
Transport - Overview

- **Water enters:** Roots absorb water and dissolved minerals from soil; exchange CO₂/O₂ within air spaces (supports cellular respiration of root cells)
- **Water moves:** Water and minerals transported upward from roots to shoots in xylem
- **Water leaves:** Loss of water vapor from leaves via stomata

How are these connected?

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Video

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III. Transport- overview

- ψ = water potential (Greek psi)
- ψ<sub>pure water</sub> = 0
- Expresses the tendency for water to diffuse or evaporate when ψ becomes negative:
  - Adhesion, evaporation, solutes will cause ψ to become negative.
- **Water moves down water potential gradients.**
- Transpiration creates negative pressure that pulls water upward through xylem; can be assisted by root pressure at night when transpiration off (more later)
Water Transport: Xylem

- **Bulk flow** thru xylem tubes pulled by negative pressure from above
- **Transpiration** – water evaporates from leaves through stomata
  - Air is drier than leaf, lower water potential
- **Adhesion** - water sticks to cell walls
- **Cohesion** - water sticks to other water molecules
- **Surface Tension** of water is high
  - (review Ch 3, hydrogen bonds)

Water Transport: Xylem

- As water evaporates from stomata, pull on other water molecules, creates negative pressure
- Pulling is transferred molecule to molecule, down stem to roots
- **Transpiration-Cohesion-Tension Theory**

Water Transport: Xylem

- Tension causes xylem cells to constrict, but rings of secondary cell walls prevent collapse (like wire rings in hose)
- About 90% of water taken in plant roots used for transpiration, 2% for photosynthesis
  - Transpires 200-1000kg of water for every 1kg of plant produced
Water Transport: Xylem

- At night, no transpiration, positive root pressure can sometimes develop and push some water up stem. But majority of water movement is by pulling!

- Cavitation – formation of air pocket in xylem, breaks chain of water molecules, pull stops. Drought stress or freezing
- Water can detour around in other vessels/tracheids
- Tracheids less susceptible. Gymnosperms do better in colder environments

Stomata Regulation

- Stomata – must get CO₂ in for photosynthesis, but also lose H₂O (trade-off)
- Guard cells – open and close stomata
  - K⁺ flows in through membrane channels
  - Causes water potential to be more negative
  - Water in by osmosis
  - Cell swells (turgid) and pulls open stomata
    - Cell wall microfibrils
    - Reverse to close stomata
Stomata Regulation

- Stomata mostly open in day and close at night
  - Light triggers receptors to turn on proton pumps
  - CO₂ depletion also triggers
  - Circadian rhythms (internal clock) also keep cycle going (even in dark)

- Hot, sunny, or windy day increases evaporation
  - If not enough water available to roots, plant loses turgor pressure, wilts

- Water deficiency triggers stomata to close
  - But slows photosynthesis and growth

V. Photosynthesis/Transpiration Compromise

- Uptake of CO₂ is positively correlated with loss of H₂O via evaporation
- Both are needed for photosynthesis
- Water conservation and photosynthesis can become a trade-off when water is limiting (e.g., arid environments)
- Can compensate by increasing water consumption (right) or limiting water loss...
V. Photosynthesis/Transpiration Compromise

- Mechanisms to reduce transpiration:
  - Fewer, tightly controlled stomata
  - Stomata on bottom of leaf, and or in wind-protected pockets
  - Small, thick leaves reduce surface area, or photosynthetic stems (cactus; spines have no stomata)
  - Thick cuticle, leathery leaves
Photosynthesis/Transpiration Compromise

- **Mechanisms to reduce transpiration:**
  - Shed leaves in dry season
    - E.g. deciduous dry forest in Costa Rica
  - **Posture**
    - Upright reduces direct exposure at mid-day
  - Carry out CO₂ uptake at night, close stomata but still photosynthesize in day (as in cactus)
Sugar Transport: Phloem

- From source, sugars move by apoplast or symplast to reach sieve-tube cells
- Sugars loaded into sieve-tube cells by active transport (living, so symplast)
  - Water moves in also by osmosis
- Bulk flow by positive pressure moves phloem sap to sink
  - Pressure builds at source thru active loading
  - Pressure reduced at sink thru unloading
- Sugar unloaded at sink by diffusion
  - Water moves out also by osmosis
- Pressure Flow hypothesis

Sugar Transport: Phloem

- Solutes (sugars) diffuse from areas of high concentration to areas of low concentration
  - Source (leaves, or stored sugar in roots)
  - To Sink (growing leaves, fruits, seeds, roots)
  - May be up or down at different times
    - Spring?
    - Summer?
Summary

• Plant growth & development and Plant transportation are intimately connected.
• Vertical growth enabled vascular plants to compete for sunlight.
• Also presented the challenges of transporting food and water throughout organism with no muscular nor nervous system.
• Vascular system of xylem and phloem addresses both of these challenges.