Plant form and function

IF3211 Domain Specific Computation

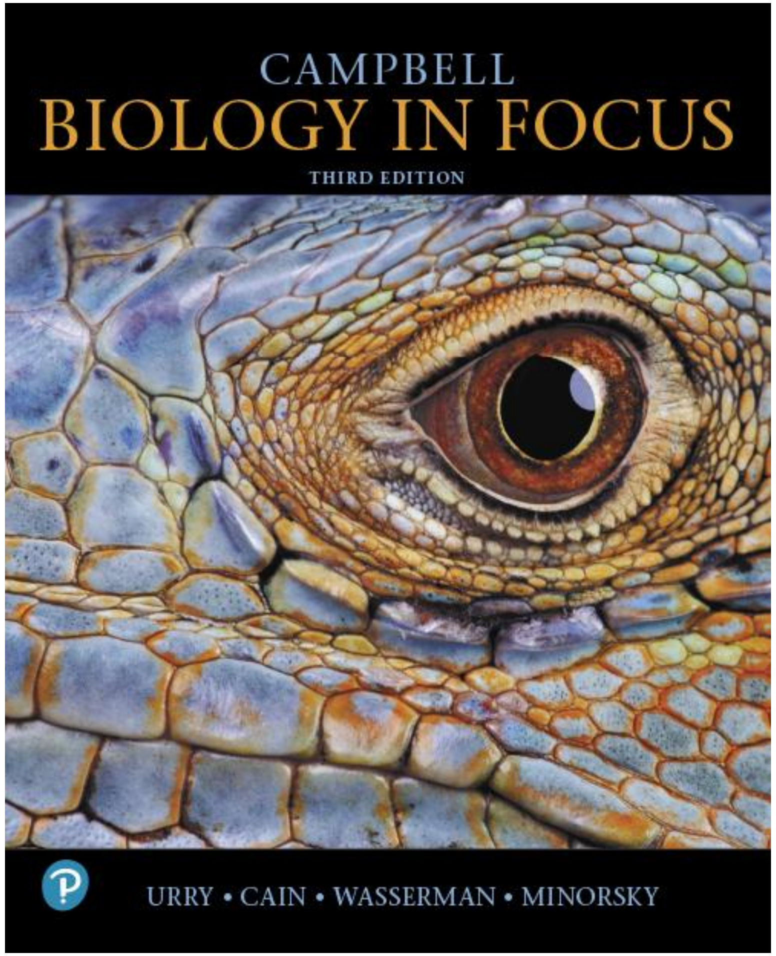
School of Electrical Engineering and Informatics ITB

Content

- Plant structure, growth and development
- Soil and plant nutrition
- Plant respond to internal and external signals

Campbell Biology in Focus

Third Edition



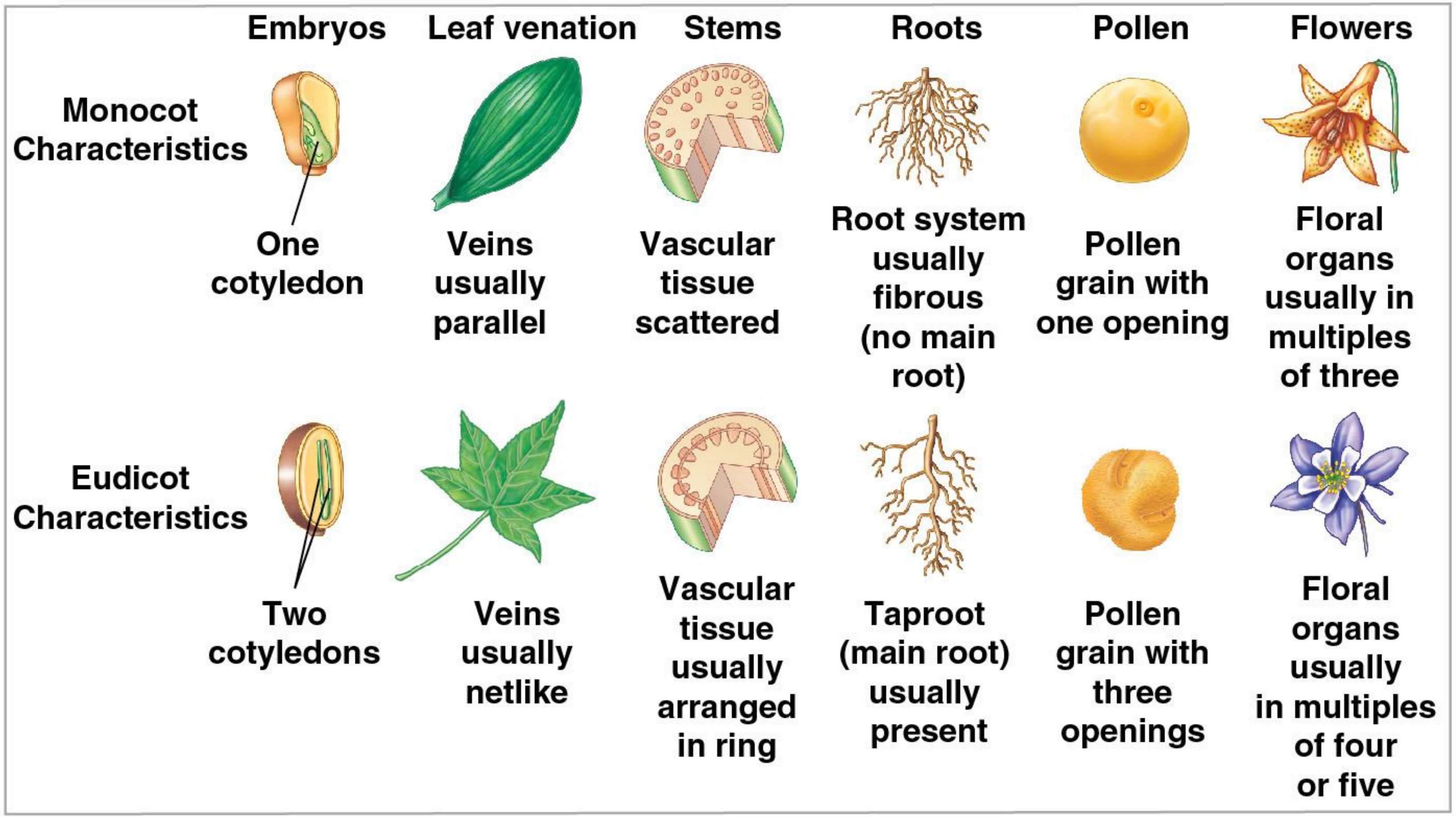
Chapter 28

Vascular Plant Structure and Growth

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Figure 28.2

Comparison of Monocots and Eudicots



Concept 28.1: Plants Have a Hierarchical Organization Consisting of Organs, Tissues, and Cells

- Plants are composed of organs, tissues, and cells
- An **organ** consists of several types of tissues that together carry out particular functions
- A **tissue** is a group of cells consisting of one or more cell types that together perform a specialized function

The Three Basic Plant Organs: Roots, Stems, and Leaves (1 of 3)

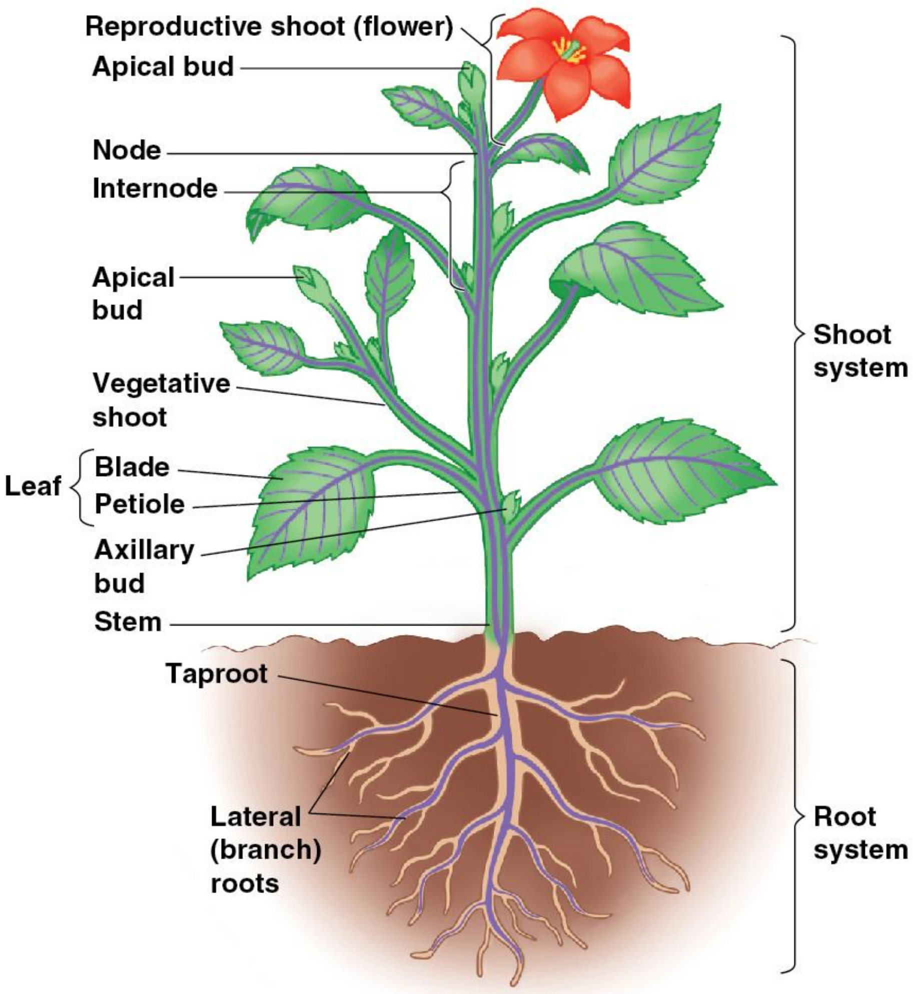
- The basic morphology of vascular plants reflects their evolution as organisms that draw resources from below ground and above ground
- Plants take up water and minerals from below ground and CO_2 and light from above ground

The Three Basic Plant Organs: Roots, Stems, and Leaves (2 of 3)

- Three basic organs evolved to acquire these resources: roots, stems, and leaves
- The **root system** includes all of the plant's roots
- The **shoot system** includes the stems, leaves, and (in angiosperms) flowers

Figure 28.3

An Overview of a Flowering Plant



The Three Basic Plant Organs: Roots, Stems, and Leaves (3 of 3)

- The root system and the shoot system are connected by vascular tissue
- Roots rely on sugar produced by photosynthesis in the shoot system
- Shoots rely on water and minerals absorbed by the root system

Roots (1 of 5)

- A **root** is an organ with important functions
  - Anchoring the plant
  - Absorbing minerals and water
  - Storing carbohydrates

Stems (1 of 2)

- A **stem** is an organ consisting of
  - An alternating series of **nodes**, the points at which leaves are attached
  - **Internodes**, the stem segments between nodes

Leaves (1 of 3)

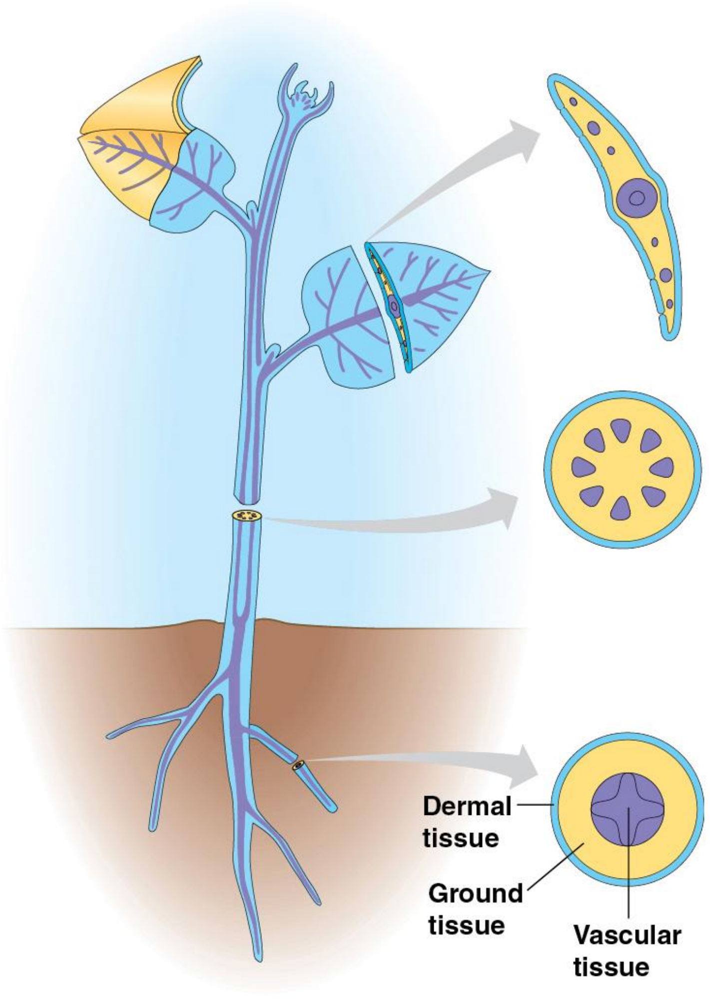
- The **leaf** is the main photosynthetic organ of most vascular plants
- Leaves have other functions, including gas exchange, dissipation of heat, and defense
- Leaves vary in form but generally consist of a flattened **blade** and a stalk called the **petiole**, which joins the leaf to the stem

Dermal, Vascular, and Ground Tissue Systems (1 of 6)

- All plant organs are composed of three tissue systems: dermal, vascular, and ground tissue
- Each tissue system is continuous throughout the plant, but the specific characteristics vary among organs

Figure 28.8

The Three Tissue Types



Common Types of Plant Cells (1 of 8)

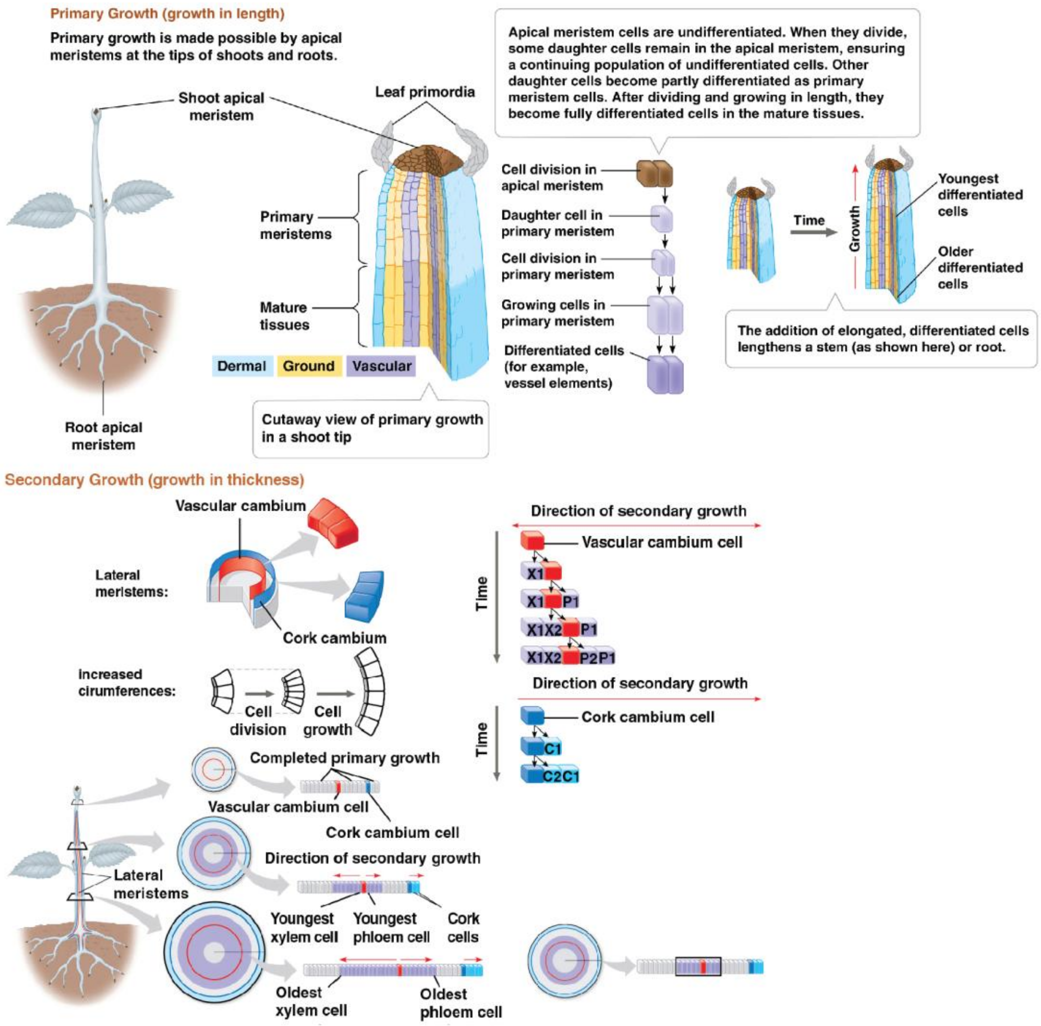
- Plant cells have structural adaptations that make their specific functions possible
- The major types of plant cells are
  - Parenchyma
  - Collenchyma
  - Sclerenchyma
  - Water-conducting cells of the xylem
  - Sugar-conducting cells of the phloem

Concept 28.2: Different Meristems Generate New Cells for Primary and Secondary Growth (1 of 6)

- A plant can grow throughout its life; this is called **indeterminate growth**
- Indeterminate growth is enabled by **meristems**, perpetually undifferentiated tissues
- Some plant organs cease to grow at a certain size; this is called **determinate growth**

Figure 28.10

Visualizing Primary and Secondary Growth



Tissue Organization of Leaves (1 of 3)

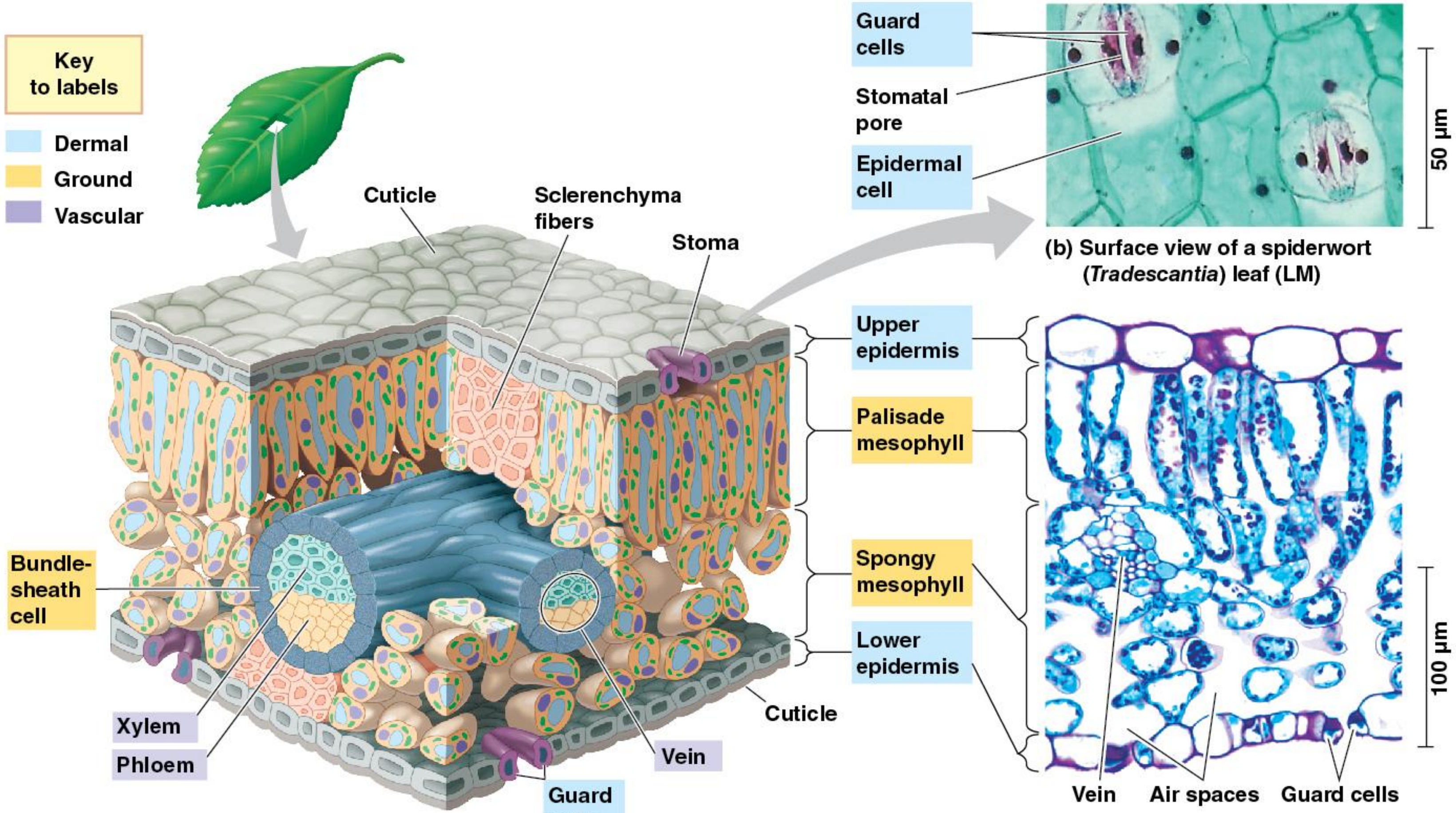
- **Stomata** are pores in the leaf epidermis that allow gas exchange between photosynthetic cells and the air surrounding the leaf
- Each stomatal pore is flanked by two **guard cells**, which regulate its opening and closing

Tissue Organization of Leaves (2 of 3)

- **Mesophyll**, the leaf's ground tissue, is composed of parenchyma cells specialized for photosynthesis
- The mesophyll of eudicots has two layers
  - The palisade mesophyll in the upper part of the leaf consists of tightly packed, elongated cells
  - The spongy mesophyll in the lower part of the leaf consists of cells loosely arranged for gas circulation

Figure 28.17

Leaf Anatomy



(a) Cutaway drawing of leaf tissues

(b) Surface view of a spiderwort (*Tradescantia*) leaf (LM)

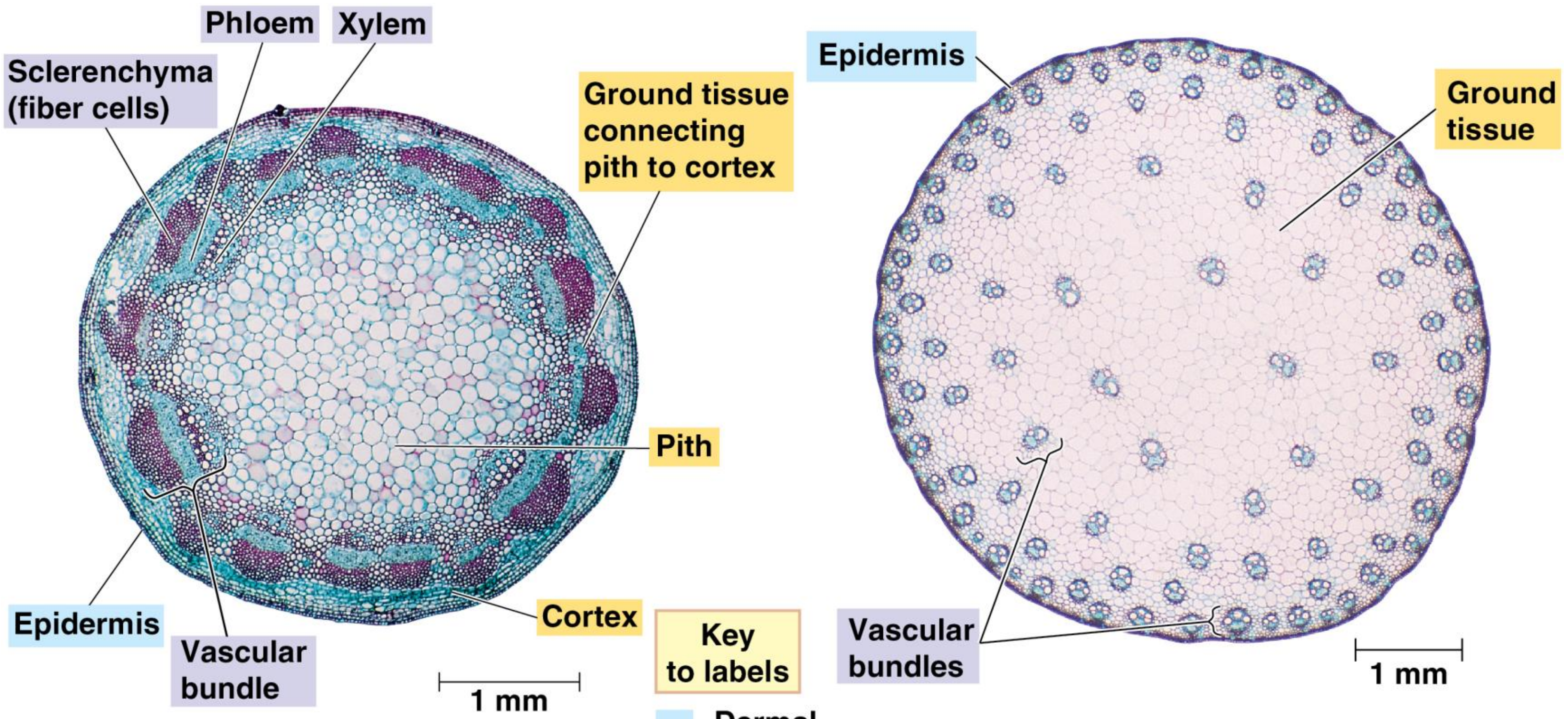
(c) Cross section of a lilac (*Syringa*) leaf (LM)

Tissue Organization of Stems (2 of 2)

- In most eudicots, the vascular tissue consists of vascular bundles arranged in a ring
- In most monocot stems, the vascular bundles are scattered throughout the ground tissue

Figure 28.18

Organization of Primary Tissues in Young Stems



(a) Cross section of stem with vascular bundles forming a ring (typical of eudicots).

(b) Cross section of stem with scattered vascular bundles (typical of monocots).

The Vascular Cambium and Secondary Vascular Tissue (1 of 7)

- The vascular cambium is a cylinder composed of a single layer of meristematic cells
- In woody stems it forms to the outside of the pith and primary xylem and to the inside of the primary phloem and cortex
- In woody roots it forms exterior to the primary xylem and interior to the primary phloem and pericycle

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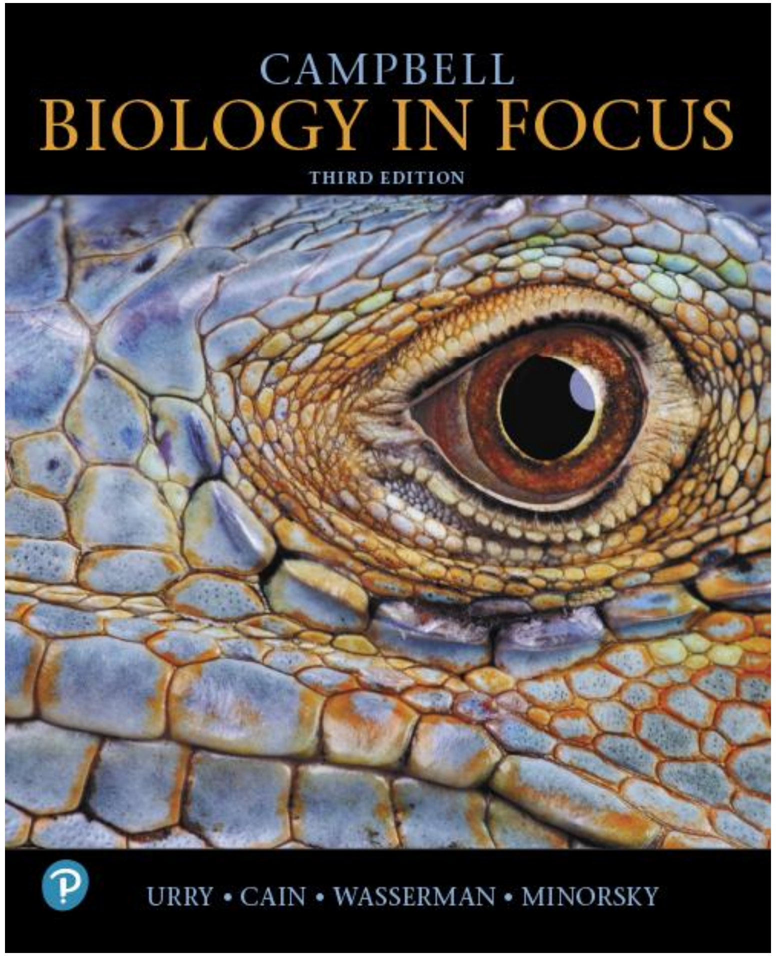


Chapter 29

Resource Acquisition, Nutrition, and Transport in Vascular Plants

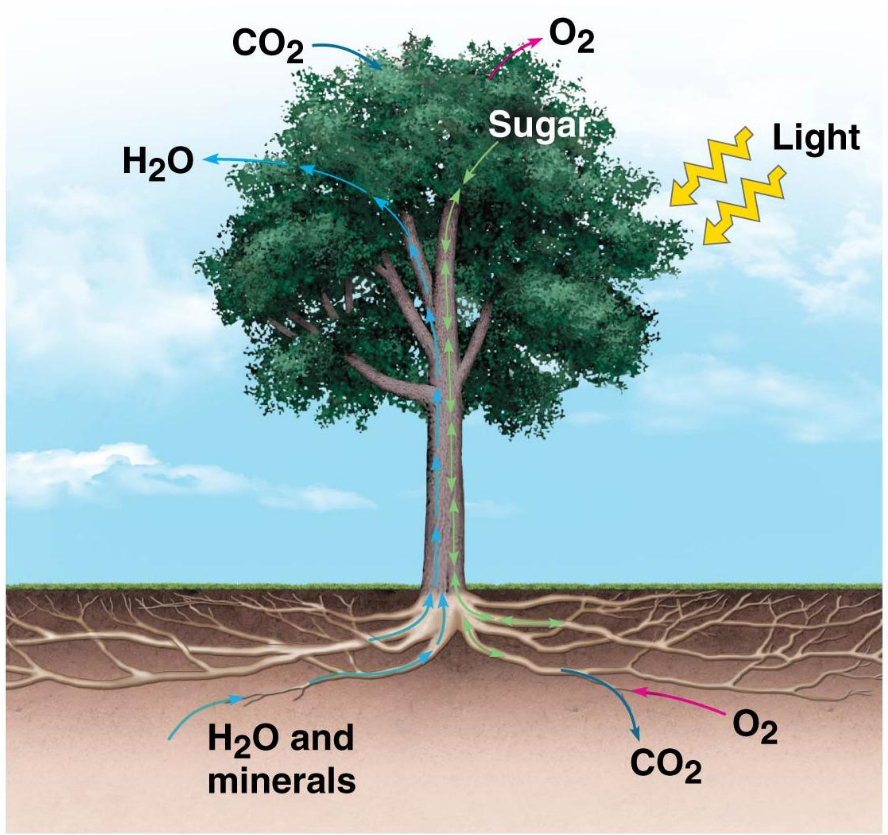
Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Concept 29.1: Adaptations for Acquiring Resources Were Key Steps in the Evolution of Vascular Plants (1 of 3)

- The algal ancestors of plants absorbed water, minerals, and CO_2 directly from surrounding water
- The colonization of land required plants to evolve adaptations to acquire resources both above and below ground

Figure 29.2

An Overview of Resource Acquisition and Transport in a Vascular Plant During the Day



Shoot Architecture and Light Capture (1 of 4)

- Plant success is generally related to photosynthesis
- Natural selection has resulted in many shoot adaptations to acquire light and CO_2 more efficiently
- Adaptations to life on land represent compromises between enhancing photosynthesis and minimizing water loss

Root Architecture and Acquisition of Water and Minerals (1 of 3)

- Soil contains resources mined by the root system
- Root growth and physiology can adjust to local conditions
  - For example, roots branch more extensively in a pocket of high nitrate than in a pocket of low nitrate
  - For example, roots respond to high soil nitrate by increasing synthesis of proteins involved in nitrate transport and assimilation

Concept 29.2: Different Mechanisms Transport Substances over Short or Long Distances

- Plants have a variety of transport processes to move a diversity of substances over a great range of distances and across barriers
- There are two major transport pathways through plants: the apoplast and the symplast

The Apoplast and Symplast: Transport Continuums (1 of 2)

- The **apoplast** consists of everything external to the plasma membrane of living cells
- It includes cell walls, extracellular spaces, and the interior of vessel elements and tracheids
- The **symplast** consists of the cytosol of all the living cells in a plant, as well as the plasmodesmata

How Solutes and Pressure Affect Water Potential (1 of 2)

- Both pressure and solute concentration affect water potential, as expressed by the water potential equation:

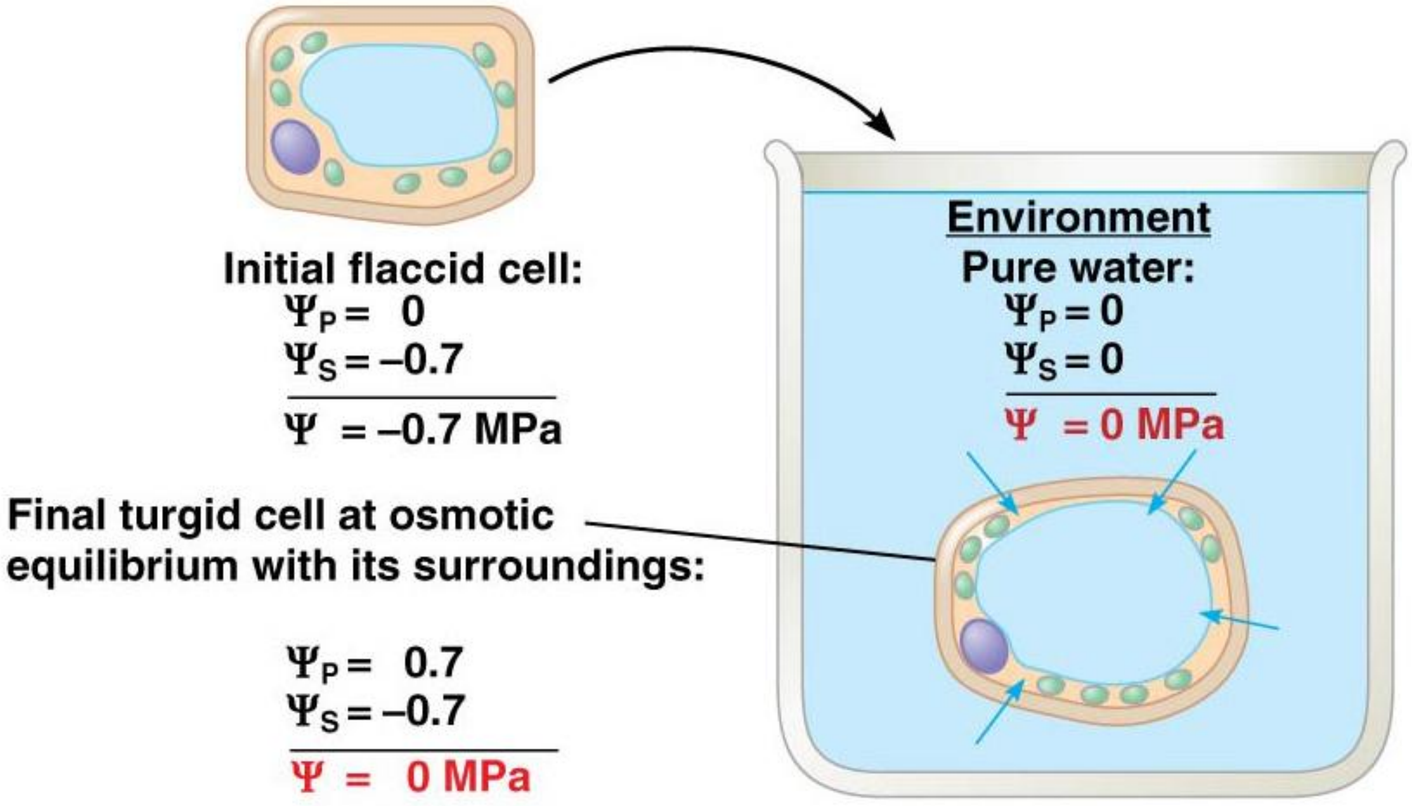
$$\Psi = \Psi_S + \Psi_P$$

- **Solute potential** (Ψ_S, also called osmotic potential) is directly proportional to molarity

- **Pressure potential** (Ψ_P) is the physical pressure on a solution; it can be positive or negative relative to atmospheric pressure

Figure 29.5 (2 of 2)

Water Relations in Plant Cells



(b) Initial conditions: cellular Ψ < environmental Ψ

Concept 29.3: Plants Roots Absorb Essential Elements from the Soil

- Water, air, and soil minerals contribute to plant growth
  - 80–90% of a plant’s fresh mass is water
  - 96% of a plant’s dry mass consists of carbohydrates from the CO_2 assimilated during photosynthesis
  - 4% of a plant’s dry mass is inorganic substances from soil

Macronutrients and Micronutrients (1 of 3)

- More than 50 inorganic chemical elements are found in plants, but not all are essential
- There are 17 **essential elements**, chemical elements required for a plant to complete its life cycle
- Researchers use **hydroponic culture**, the growth of plants in mineral solutions, to determine which chemical elements are essential

Figure 29.8

Research Method: Hydroponic Culture

Control: Solution containing all minerals

Experimental: Solution without iron

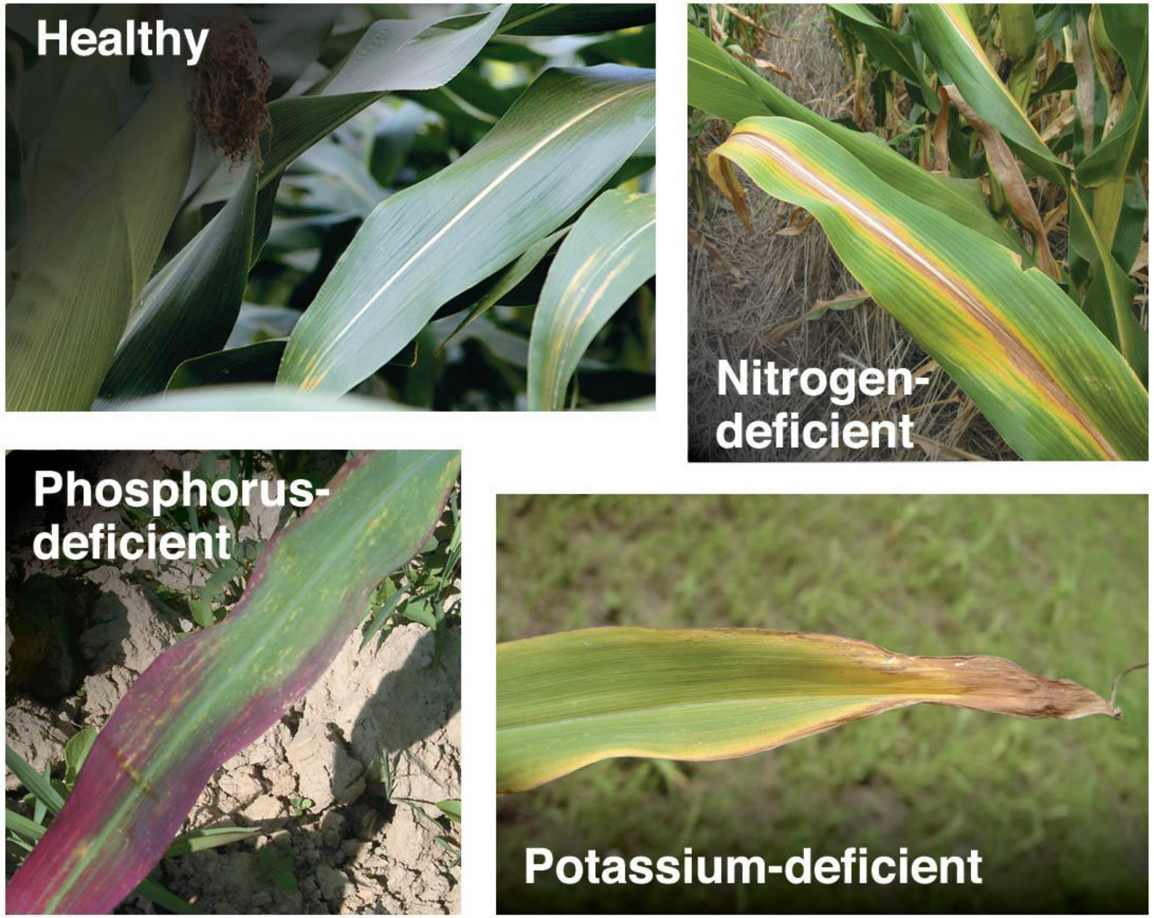
Table 29.1

Macronutrients in Plants

Element	Form Primarily Absorbed by Plants	Percent Mass in Dry Tissue	Major Functions
Carbon	CO_2	45%	Major component of plant's organic compounds
Oxygen	CO_2	45%	Major component of plant's organic compounds
Hydrogen	H_2O	6%	Major component of plant's organic compounds
Nitrogen	NO_3^-, NH_4^+	1.5%	Component of nucleic acids, proteins, and chlorophyll
Potassium	K^+	1.0%	Cofactor of many enzymes; major solute functioning in water balance; operation of stomata
Calcium	Ca^{2+}	0.5%	Important component of middle lamella and cell walls; maintains membrane function; signal transduction
Magnesium	Mg^{2+}	0.2%	Component of chlorophyll; cofactor of many enzymes
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	0.2%	Component of nucleic acids, phospholipids, ATP
Sulfur	SO_4^{2-}	0.1%	Component of proteins

Figure 29.9

Common Mineral Deficiencies, as Seen in Maize Leaves



Soil Management

- Ancient farmers recognized that crop yields would decrease on a particular plot over the years
- Soil management, by fertilization and other practices, allowed for sedentary agriculture and the first permanent villages

The Living, Complex Ecosystem of Soil

- Most terrestrial plants grow in soil, obtaining most of their mineral nutrients from the topsoil
- The basic physical properties of soil, such as texture and composition, are major determinants of soil quality and plant nutrition

Soil Texture (1 of 2)

- Soil particles are classified by size; from largest to smallest they are called sand, silt, and clay
- Weathering rocks release mineral particles that mix with living organisms and humus to form topsoil
- Soil solution consists of water and dissolved minerals in the pores between soil particles
- The pores also contain air pockets

Bacteria and Plant Nutrition

- Soil bacteria can benefit plants by
  - Exchanging beneficial chemicals with plant roots
  - Increasing nutrient availability by decomposing dead organic materials
  - Converting nitrogen from the air

Fungi and Plant Nutrition (1 of 2)

- **Mycorrhizae** are mutualistic associations of fungi and plant roots
- The host plant benefits the fungus by providing a steady supply of sugar
- The fungus benefits the host plant by increasing surface area for water and mineral absorption

Mycorrhizae and Plant Evolution

- Most plants form mycorrhizae
- Neither early plants nor fungi were fully equipped to exploit the terrestrial environment
- Fossil evidence indicates that mycorrhizae were an early adaptation that helped plants and fungi colonize the land together

Epiphytes, Parasitic Plants, and Carnivorous Plants (1 of 4)

- Some plants have nutritional adaptations that use other organisms in nonmutualistic ways
- Three unusual adaptations are
  - Epiphytes
  - Parasitic plants
  - Carnivorous plants

Figure 29.16

Exploring Unusual Nutritional Adaptations in Plants

Staghorn fern, an epiphyte

Parasitic Plants

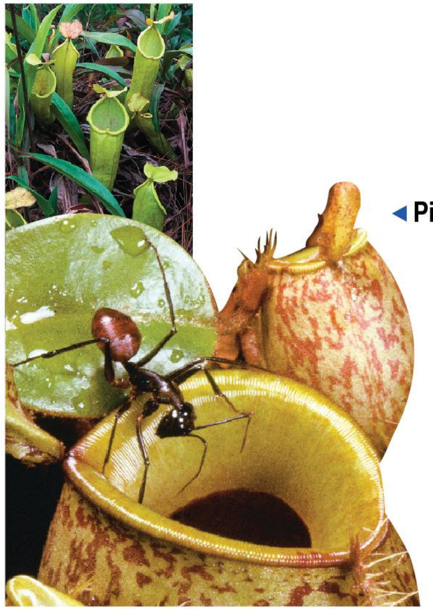
Mistletoe, a photosynthetic parasite

Dodder, a nonphotosynthetic parasite (orange)

Indian pipe, a nonphotosynthetic parasite of mycorrhizae

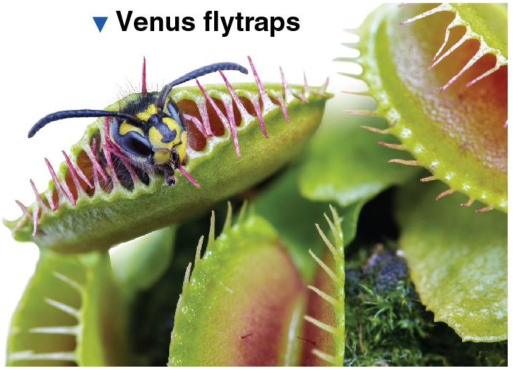
Carnivorous Plants

▲ Sundew



◀ Pitcher plants

▼ Venus flytraps



Concept 29.6: The Rate of Transpiration is Regulated by Stomata

- Leaves generally have large surface areas and high surface-to-volume ratios
- These characteristics increase both photosynthesis and water loss through stomata
- Guard cells open and close the stomata to help balance water conservation with gas exchange

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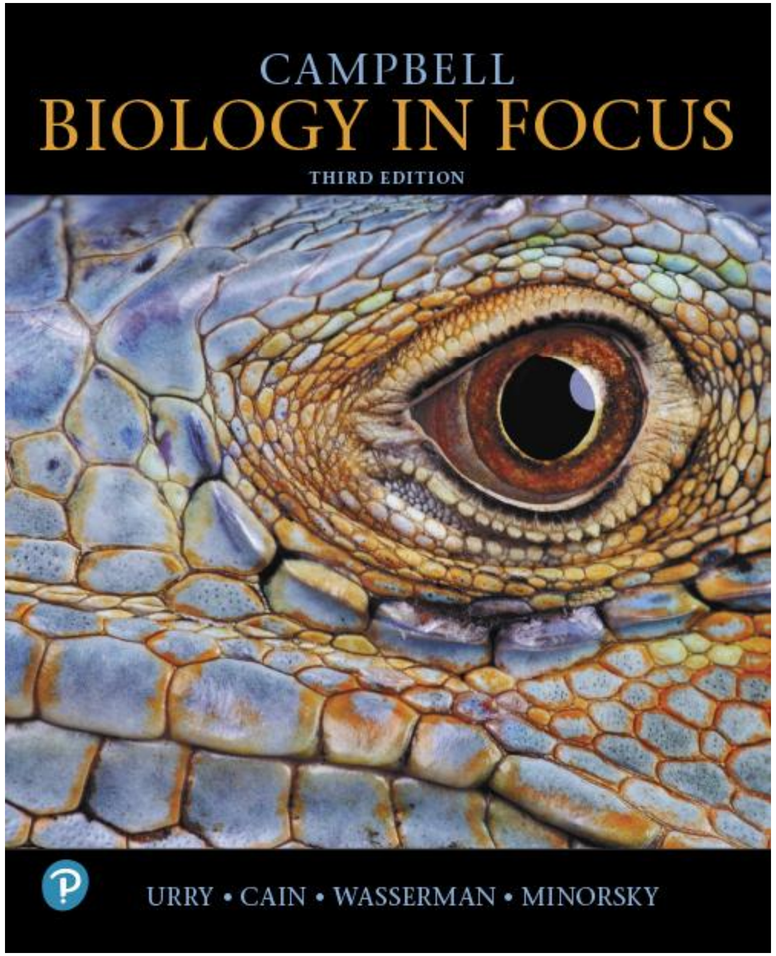


Chapter 31

Plant Responses to Internal and External Signals

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Overview: Stimuli and a Stationary Life

- Unlike animals, which respond through movement, plants must respond to environmental challenges by altering their growth and development
  - For example, the growth of a parasitic dodder (*Cuscuta*) seedling toward a host plant occurs in response to chemicals released by the host

Figure 31.1 (2 of 2)

A Vampire Plant?

Concept 31.1: Plant Hormones Help Coordinate Growth, Development, and Responses to Stimuli (1 of 3)

- Plant **hormones** are chemical signals that modify or control one or more specific physiological processes within a plant

The Discovery of Plant Hormones (2 of 4)

- Early experiments on phototropism were conducted by Charles Darwin and his son Francis in 1880
- They showed that grass seedlings could only bend toward light if the coleoptile tip was present and exposed to light
- They postulated that a signal was transmitted from the tip to the elongating region of the coleoptile

A Survey of Plant Hormones

- The five classic plant hormones include
  - Auxin
  - Cytokinins
  - Gibberellins
  - Abscisic acid
  - Ethylene

Concept 31.2: Responses to Light Are Critical for Plant Success

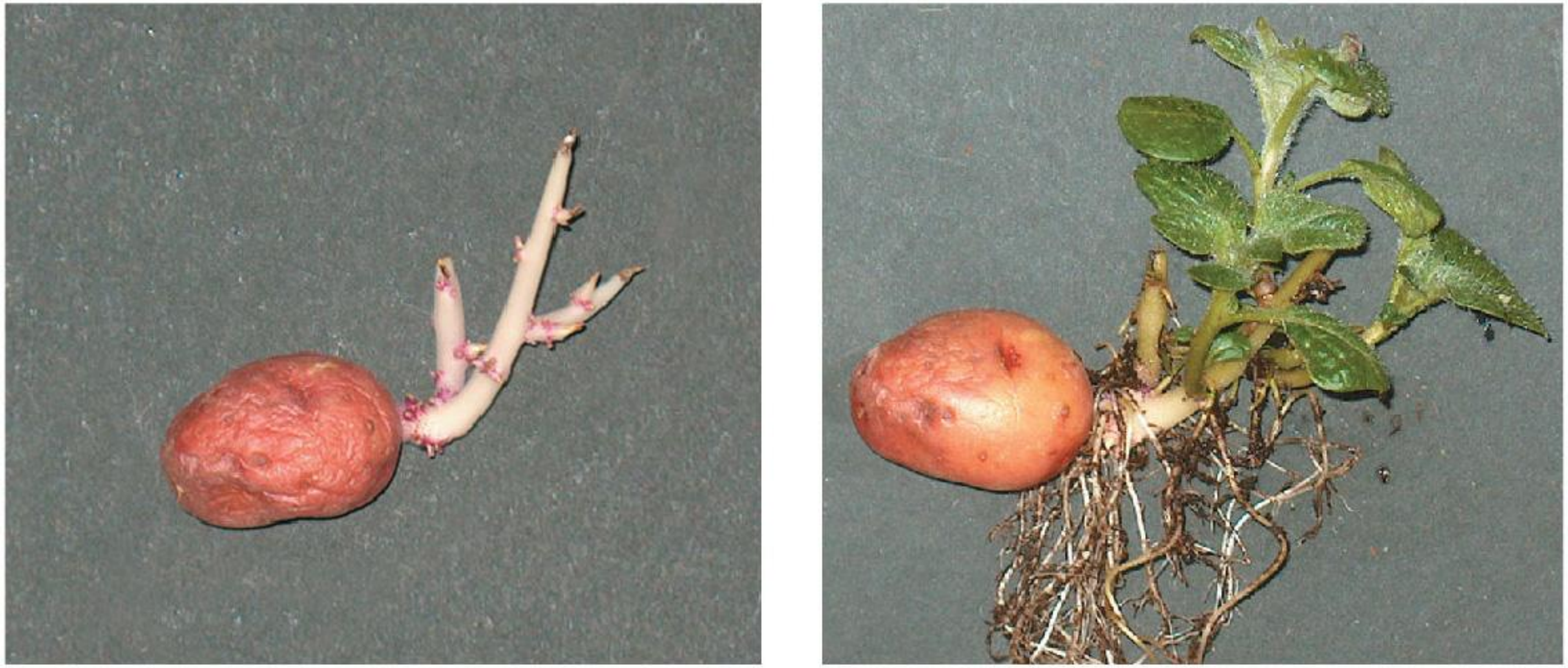
- Light triggers many key events in plant growth and development, collectively known as **photomorphogenesis**

Photomorphogenesis (1 of 3)

- Plants have morphological adaptations for growing in darkness, collectively called **etiolation**
  - For example, a potato left in the dark produces shoots with pale stems and unexpanded leaves, and short, stubby roots
- Exposure to light causes plants to undergo changes collectively called **de-etiolation**; root and shoot growth returns to normal

Figure 31.11

Light-Induced De-Etiolation (Greening) of Dark-Grown Potatoes



(a) Before exposure to light

(b) After a week's exposure to natural daylight

Blue-Light Photoreceptors

- Plants use different types of photoreceptor pigments to detect and initiate responses to blue light
  - For example, cryptochromes are involved in initiating blue-light-induced inhibition of stem elongation
  - Phototropin mediates blue-light-induced stomatal opening, chloroplast movement, and phototropism

Phytochrome Photoreceptors

- Phytochromes are photoreceptors that regulate many responses to light, including seed germination and shade avoidance

Biological Clocks and Circadian Rhythms (1 of 2)

- Many plant processes oscillate during the day independent of environmental conditions
  - For example, many legumes lower their leaves in the evening and raise them in the morning, even when kept under constant light or dark conditions

Figure 31.15

"Sleep Movements" of a Bean Plant (*Phaseolus vulgaris*)

Noon **10:00 PM**

The Effect of Light on the Biological Clock

- Both phytochromes and blue-light photoreceptors can entrain circadian rhythms in plants
- Phytochrome conversion marks sunrise and sunset, providing the biological clock with environmental cues

Photoperiodism and Responses to Seasons

- Plants use changes in day length (photoperiod) as the environmental cue to detect the time of year
- **Photoperiodism** is a physiological response to specific night or day lengths

Photoperiodism and Control of Flowering

- In many species, onset of flowering occurs when the photoperiod changes relative to a critical light period
- Plants that flower when a light period is shorter than a critical length are called **short-day plants**
- Plants that flower when a light period is longer than a critical length are called **long-day plants**
- Flowering in **day-neutral plants** is controlled by plant maturity, not photoperiod

Concept 31.3: Plants Respond to a Wide Variety of Stimuli Other Than Light

- Because they are immobile, plants must adjust to a range of environmental circumstances through developmental and physiological mechanisms

Gravity (1 of 2)

- Response to gravity is called **gravitropism**
- Roots show positive gravitropism by growing downward; shoots show negative gravitropism by growing upward
- Plants may detect gravity by the settling of **statoliths**, dense cytoplasmic components

Mechanical Stimuli (1 of 3)

- The term **thigmomorphogenesis** refers to changes in form that result from mechanical disturbance
- Rubbing stems of young plants a couple of times daily results in plants that are shorter than controls

Figure 31.21

Rapid Turgor Movements by the Sensitive Plant (*Mimosa pudica*)

(a) Unstimulated state (leaflets spread apart)

(b) Stimulated state (leaflets folded)

Environmental Stresses

- Environmental stresses can have adverse effects on plant survival, growth, and reproduction
- Stresses can be **abiotic** (nonliving) or **biotic** (living)
- Biotic stresses include herbivores and pathogens
- Abiotic stresses include drought, flooding, salt stress, heat stress, and cold stress

Drought

- Water loss due to transpiration can cause a plant to wilt and eventually die in drought conditions
- Plants can reduce transpiration by closing stomata, reducing exposed leaf surface, or shedding leaves
- These responses conserve water but also reduce photosynthesis, which diminishes crop yield

Flooding

- Plants may suffocate in waterlogged soils, which lack air spaces required for roots to obtain oxygen
- Production of ethylene kills root cortex cells, creating air tubes that function as “snorkels” to provide oxygen to submerged roots

Salt Stress

- Salt can reduce water uptake by lowering the water potential of the soil solution
- Sodium can be toxic in high concentration
- Some plants produce solutes tolerated at high concentrations that reduce the water potential of their cells relative to the soil solution
- Halophytes have adaptations that allow them to tolerate salt stress for long periods

Heat Stress

- Excessive heat can harm or kill a plant by denaturing its enzymes
- Transpiration cools leaves, but stomata close at high temperatures reducing water loss
- **Heat-shock proteins** are produced at high temperature and protect other proteins from denaturing during heat stress

Cold Stress (1 of 3)

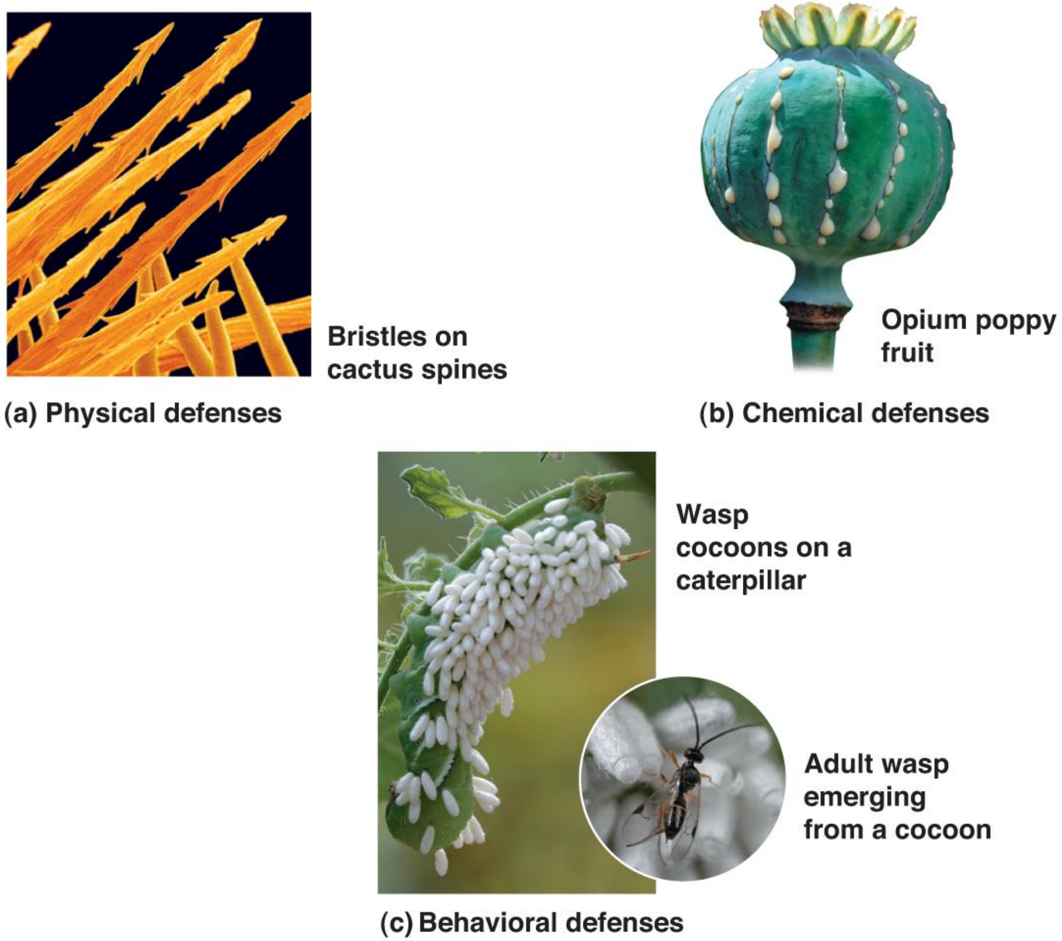
- Cold temperatures decrease the fluidity of cell membranes, altering solute transport and membrane protein function
- Membrane lipids increase in their proportion of unsaturated fatty acids to maintain fluidity during cold conditions

Concept 31.4: Plants Respond to Attacks by Herbivores and Pathogens

- Plants have evolved defense systems that deter attack by a diversity of pathogens and plant-eating (herbivorous) animals

Figure 31.23 (1 of 4)

Some Defense Responses Against Herbivores



The Hypersensitive Response

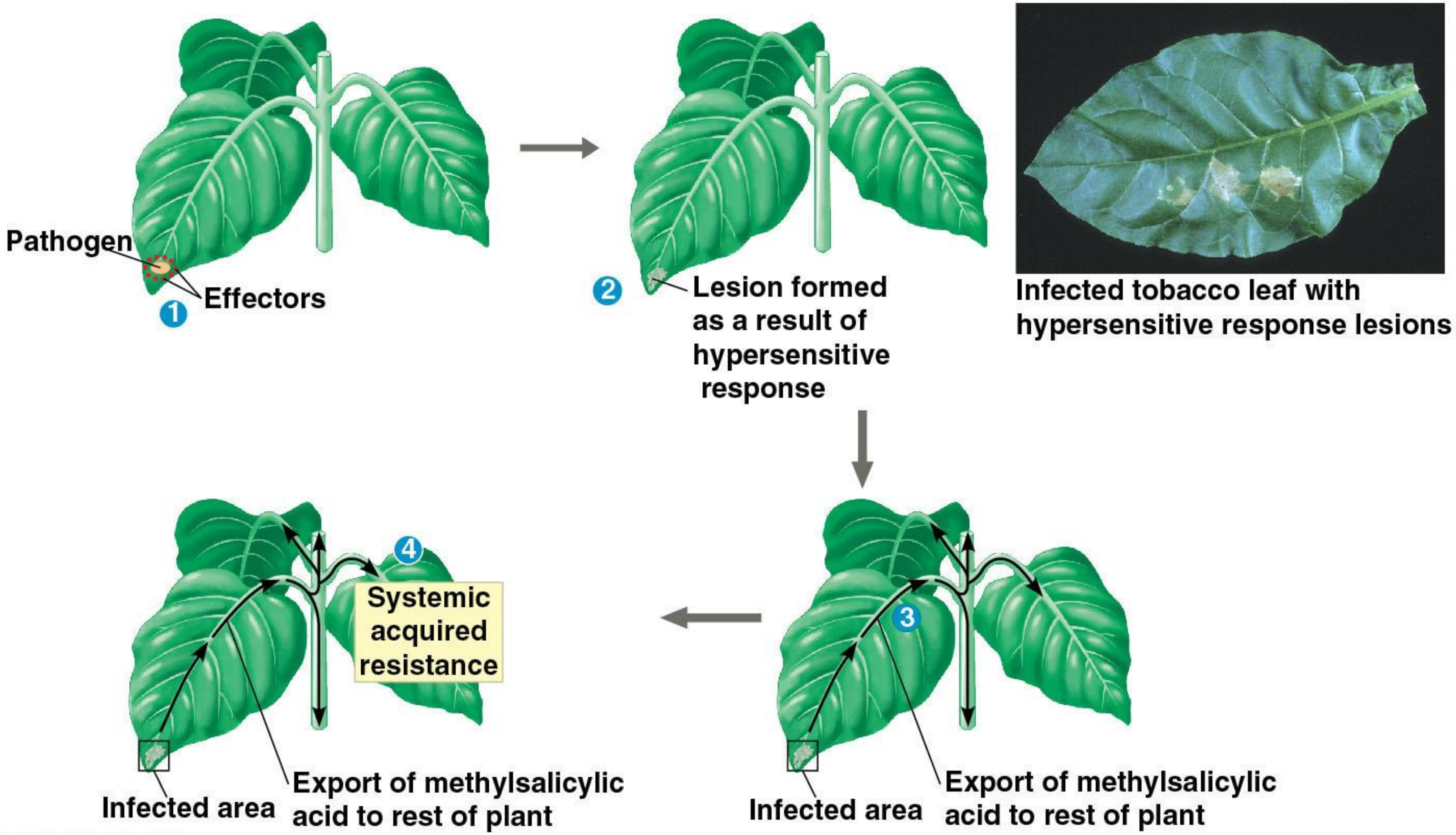
- This response causes localized cell death near the infection site and restricts the spread of the pathogen
- The plant produces enzymes and chemicals that damage the pathogen's cell wall, metabolism, or reproduction

Systemic Acquired Resistance

- **Systemic acquired resistance** causes plant-wide expression of defense genes and provides a long-lasting response to a diversity of pathogens
- Methylsalicylic acid travels from an infection site to remote areas of the plant, where it is converted to **salicylic acid**, which initiates pathogen resistance

Figure 31.24

Effector-Triggered Defense Responses Against Pathogens



Copyright

Computing Tools

Several Computing Tasks

Modeling Plant Growth and Development

Simulation of plant growth using algorithms (e.g., L-systems for modeling branching patterns).

Genetic Algorithms and Plant Breeding

Use of genetic algorithms to simulate artificial selection.

Machine Learning: Plant Diversity and Distribution

Statistical-based technique for diversity data. Basic image processing to quantify features of flowers (e.g., petal count, symmetry).

Modeling Plant Growth and Development

Simulation of plant growth using algorithms

- L-systems for modeling branching patterns
- An L-system is a parallel rewriting system and a type of formal grammar. It consists of an alphabet of symbols, a set of production rules, an initial axiom (starting string), and a mechanism for translating the resulting strings into geometric structures.

Prusinkiewicz, P., & Lindenmayer, A. (1990). *The Algorithmic Beauty of Plants*. Springer-Verlag.

https://algorithmicbotany.org/papers/abop/abop.pdf

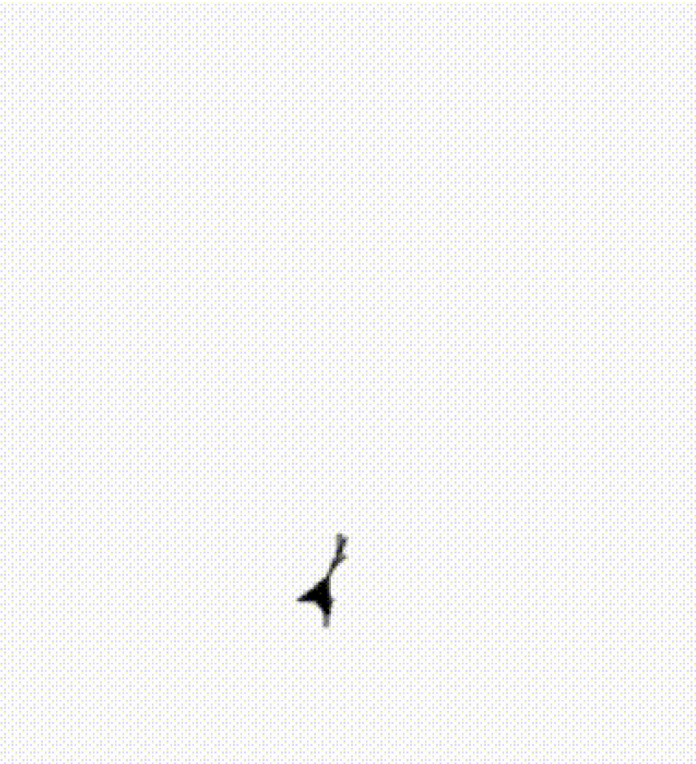
Modeling Plant Growth and Development

How does it work?

- **Axiom:** The starting string (e.g., "F").
- **Rules:** Define how each symbol is replaced (e.g., "F" → "F[+F]F[-F]F").
- **Iterations:** Apply rules repeatedly to generate complex structures.
- **Interpretation:** Symbols are interpreted as drawing commands (e.g., "F" = move forward, "+" = turn right, "-" = turn left, "[" = push position, "]" = pop position).

Example: Simple Binary Tree L-system

- **Axiom:** "F"
- **Rules:** "F" → "F[+F]F[-F]F"
- **Angle:** 25°
- **Iterations:** 4



Genetic Algorithms and Plant Breeding

Use of genetic algorithms to simulate artificial selection of parental lines for plant breeding

Chung PY, Liao CT. *Selection of parental lines for plant breeding via genomic prediction*. Front Plant Sci. 2022.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9363737/

Genetic Algorithms and Plant Breeding

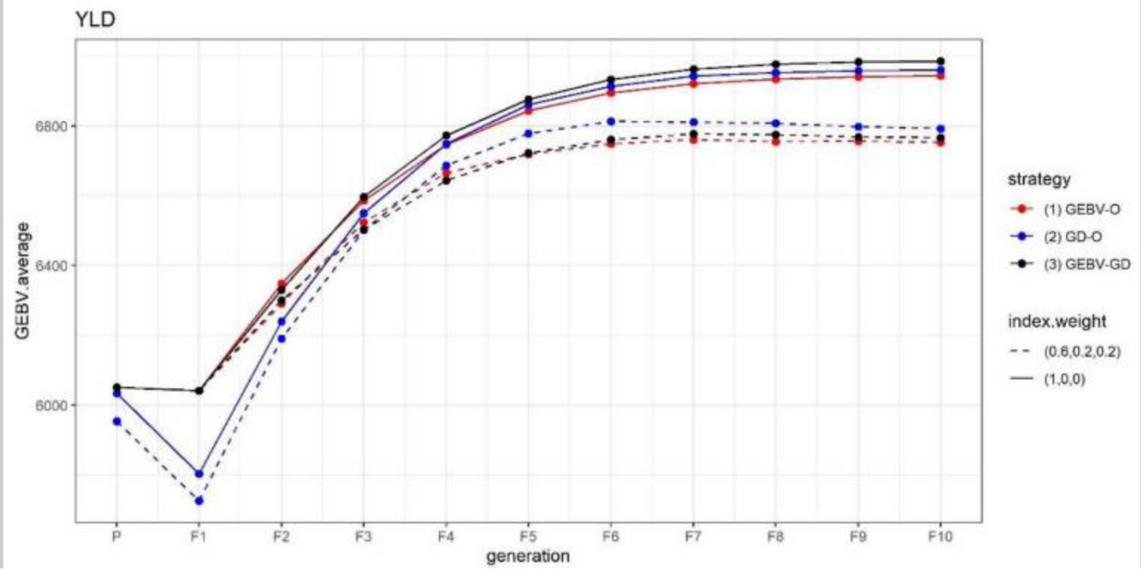
This research presents a genomic prediction approach to identify superior parental lines for multi-trait selection in plant breeding.

The authors propose a novel selection index that integrates genomic-estimated breeding values (GEBVs) and genomic diversity, optimizing the choice of parents for breeding programs.

The method is demonstrated on rice datasets and is supported b
practical use.

Key Points:

- Integrates genomic prediction and diversity for optimal paren
- Demonstrated on real rice breeding data.
- Provides an R package (IPLGP) for breeders and researchers.



Machine Learning: Plant Diversity and Distribution

Machine learning for plant diversity data. Basic image processing to quantify features of flowers (e.g., petal count, symmetry).

E. Nilsback and A. Zisserman, *Automated Flower Classification over a Large Number of Classes*, 2008 Sixth Indian Conference on Computer Vision, Graphics & Image Processing, Bhubaneswar, India, 2008, IEEE

https://ieeexplore.ieee.org/document/4756141

Data Analysis: Plant Diversity and Distribution

presents a method for automated classification of flowers using a large dataset (103 classes). The authors extract features describing shape, texture, and spatial distribution, and use these for classification, which is closely related to analyzing plant diversity and distribution in large datasets.