Cellular Communication In Plants

Plasmodesmata
Plant Hormones
Tropisms
Plasmodesmata in Plant Cells

- **Plasmodesmata** are channels that perforate plant cell walls
- Through plasmodesmata, water and small solutes (and sometimes proteins and RNA) can pass from cell to cell
Figure 6.31

- Interior of cell
- Plasmodesmata
- Plasma membranes
- Cell walls
- 0.5 µm
Concept 39.1: Signal transduction pathways link signal reception to response

- A potato left growing in darkness produces shoots that look unhealthy, and it lacks elongated roots.
- These are morphological adaptations for growing in darkness, collectively called **etiolation**.
- After exposure to light, a potato undergoes changes called **de-etiolation**, in which shoots and roots grow normally.
Figure 39.2

(a) Before exposure to light  
(b) After a week’s exposure to natural daylight

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• A potato’s response to light is an example of cell-signal processing
• The stages are reception, transduction, and response
Figure 39.3

1. Reception
2. Transduction
3. Response

Relay proteins and second messengers
Activation of cellular responses

Receptor
Hormone or environmental stimulus

Plasma membrane

CELL WALL

CYTOPLASM

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Reception

- Internal and external signals are detected by receptors, proteins that change in response to specific stimuli
- In de-etiolation, the receptor is a phytochrome capable of detecting light
Transduction

- **Second messengers** transfer and amplify signals from receptors to proteins that cause responses
- Two types of second messengers play an important role in de-etiolation: Ca\(^{2+}\) ions and cyclic GMP (cGMP)
- The phytochrome receptor responds to light by
  - Opening Ca\(^{2+}\) channels, which increases Ca\(^{2+}\) levels in the cytosol
  - Activating an enzyme that produces cGMP
Figure 39.4-1

Reception

CYTOPLASM

Plasma membrane

Phytochrome

Cell wall

Light
Figure 39.4-2

1 Reception

2 Transduction

CYTOPLASM

- Plasma membrane
- Phytochrome
- Cell wall
- Light

Second messenger
- cGMP
- Protein kinase 1
- Protein kinase 2

Ca²⁺ channel
- Ca²⁺

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Figure 39.4-3

1 Reception

2 Transduction

3 Response

CYTOPLASM

Plasma membrane

Phytochrome

Second messenger

cGMP

Protein kinase 1

Protein kinase 2

Ca^{2+} channel

Ca^{2+}

Cell wall

Light

Nucleus

Transcription factor 1

Transcription factor 2

Transcription

Translation

De-etiolation (greening) response proteins

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Response

- A signal transduction pathway leads to regulation of one or more cellular activities
- In most cases, these responses to stimulation involve increased activity of enzymes
- This can occur by transcriptional regulation or post-translational modification
The Discovery of Plant Hormones

• Any response resulting in curvature of organs toward or away from a stimulus is called a **tropism**
• In the late 1800s, Charles Darwin and his son Francis conducted experiments on **phototropism**, a plant’s response to light
• They observed that a grass seedling could bend toward light only if the tip of the coleoptile was present
<table>
<thead>
<tr>
<th>Plant Hormone</th>
<th>Major Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxin</td>
<td>Stimulates cell elongation; regulates branching and organ bending.</td>
</tr>
<tr>
<td>Cytokininns</td>
<td>Stimulate plant cell division; promote later bud growth; slow organ death.</td>
</tr>
<tr>
<td>Gibberellins</td>
<td>Promote stem elongation; help seeds break dormancy and use stored reserves.</td>
</tr>
<tr>
<td>Brassinosteroids</td>
<td>Chemically similar to the sex hormones of animals; induce cell elongation and division.</td>
</tr>
<tr>
<td>Abscisic acid</td>
<td>Promotes stomatal closure in response to drought; promotes seed dormancy.</td>
</tr>
<tr>
<td>Strigolactones</td>
<td>Regulate apical dominance, seed germination, and mycorrhizal associations.</td>
</tr>
<tr>
<td>Ethylene</td>
<td>Mediates fruit ripening.</td>
</tr>
</tbody>
</table>
Plant Hormones

- Auxins
- Gibberellins
- Cytokinins
- Ethylene
- and more…
Auxin (IAA)

- Effects
  - controls cell division & differentiation
  - creates tropisms!
    - growth towards light
    - asymmetrical distribution of auxin
    - cells on darker side elongate faster than cells on brighter side
  - Phototropism
Auxin

- The term **auxin** refers to any chemical that promotes elongation of coleoptiles
- Indoleacetic acid (IAA) is a common auxin in plants; in this lecture the term **auxin** refers specifically to IAA
- Auxin is produced in shoot tips and is transported down the stem
- Auxin transporter proteins move the hormone from the basal end of one cell into the apical end of the neighboring cell
The Role of Auxin in Cell Elongation

- According to the acid growth hypothesis, auxin stimulates proton pumps in the plasma membrane.
- The proton pumps lower the pH in the cell wall, activating *expansins*, enzymes that loosen the wall’s fabric.
- With the cellulose loosened, the cell can elongate.
Figure 39.8

Cross-linking polysaccharides

Cell wall–loosening enzymes

Expansin

Cellulose microfibril

CELL WALL

Plasma membrane

CYTOPLASM

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Cytokinins

- Cytokinins are so named because they stimulate cytokinesis (cell division)
- Cytokinins are produced in actively growing tissues such as roots, embryos, and fruits
- Cytokinins work together with auxin to control cell division and differentiation

Anti-Aging Effects
- Cytokinins slow the aging of some plant organs by inhibiting protein breakdown, stimulating RNA and protein synthesis, and mobilizing nutrients from surrounding tissues
Gibberellins

- Family of hormones
  - over 100 different gibberellins identified
- Effects
  - stem elongation
  - Seed germination

Plump grapes in grocery stores have been treated with gibberellin hormones while on the vine.
Germination

• After water is imbibed, release of gibberellins from the embryo signals seeds to germinate
(a) Rosette form (left) and gibberellin-induced bolting (right)
Abscisic Acid

- Abscisic acid (ABA) slows growth
- Two of the many effects of ABA
  - Seed dormancy
  - Drought tolerance
Seed Dormancy

• Seed dormancy ensures that the seed will germinate only in optimal conditions
• In some seeds, dormancy is broken when ABA is removed by heavy rain, light, or prolonged cold
• Precocious (early) germination can be caused by inactive or low levels of ABA
Drought Tolerance

• ABA is the primary internal signal that enables plants to withstand drought
• ABA accumulation causes stomata to close rapidly
Abscisic acid (ABA)

• Effects
  – close stomata
  – seed germination
  – high concentrations of abscisic acid
    – germination only after ABA is inactivated or leached out

• survival value:
  seed will germinate only under optimal conditions
    – light, temperature, moisture
Ethylene

- Plants produce **ethylene** in response to stresses such as drought, flooding, mechanical pressure, injury, and infection
- The effects of ethylene include response to mechanical stress, senescence, leaf abscission, and fruit ripening
Fruit Ripening

- A burst of ethylene production in a fruit triggers the ripening process
- Ethylene triggers ripening, and ripening triggers release of more ethylene
- Fruit producers can control ripening by picking green fruit and controlling ethylene levels
Senescence

- **Senescence** is the programmed death of cells or organs

- A burst of ethylene is associated with apoptosis, the programmed destruction of cells, organs, or whole plants
Leaf Abscission

• A change in the balance of auxin and ethylene controls leaf abscission, the process that occurs in autumn when a leaf falls
Ethylene

• Hormone gas released by plant cells

• Effects
  – Fruit ripening
  – Senescence
    • like in Autumn
    • apoptosis

One bad apple spoils the whole bunch...
Fruit ripening

• Adaptation
  – hard, tart fruit protects developing seed from herbivores
  – ripe, sweet, soft fruit attracts animals to disperse seed

• Mechanism
  – triggers ripening process
    • breakdown of cell wall
      – softening
    • conversion of starch to sugar
      – sweetening
  – positive feedback system
    • ethylene triggers ripening
    • ripening stimulates more ethylene production
      – clusters of fruit ripen together
Apoptosis in plants

- Many events in plants involve apoptosis
  - response to hormones
    - ethylene
    - auxin
  - death of annual plant after flowering
    - senescence
  - differentiation of xylem vessels
    - loss of cytoplasm
  - shedding of autumn leaves

What is the evolutionary advantage of loss of leaves in autumn?
Photoperiodism and Control of Flowering

• Some processes, including flowering in many species, require a certain photoperiod
• 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 certain number of hours are called long-day plants
• Flowering in day-neutral plants is controlled by plant maturity, not photoperiod
• Phytochromes exist in two photoreversible states, with conversion of $P_r$ to $P_{fr}$ triggering many developmental responses
• Red light triggers the conversion of $P_r$ to $P_{fr}$
• Far-red light triggers the conversion of $P_{fr}$ to $P_r$
• The conversion to $P_{fr}$ is faster than the conversion to $P_r$
• Sunlight increases the ratio of $P_{fr}$ to $P_r$, and triggers germination
Figure 39.19

Synthesis

\[ \text{Pr} \rightarrow \]

Red light

Far-red light

Slow conversion in darkness (some plants)

\[ \text{P}_{\text{fr}} \rightarrow \]

Responses: seed germination, control of flowering, etc.

Enzymatic destruction
The Effect of Light on the Biological Clock

• Phytochrome conversion marks sunrise and sunset, providing the biological clock with environmental cues
Photoperiodism and Responses to Seasons

• Photoperiod, the relative lengths of night and day, is the environmental stimulus plants use most often to detect the time of year

• **Photoperiodism** is a physiological response to photoperiod
• Some plants flower after only a single exposure to the required photoperiod
• Other plants need several successive days of the required photoperiod
• Still others need an environmental stimulus in addition to the required photoperiod
  – For example, vernalization is a pretreatment with cold to induce flowering