Plant Sensory Systems

182 Bonine
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(Freeman Ch38)
Plant Sensory Systems, Signals, and Responses

- Plants process information
- Environmental stimuli affect ability to grow and reproduce...
  - wavelength of light, photoperiod, time of day
  - gravity, mechanical stimulation (touch or wind)
  - disease-causing agents and herbivores
When sensory cells receive a stimulus, they transduce the signal and respond by producing hormones that carry information to target cells elsewhere in the body.

Hormones produce a response by acting on target cells.
Information Processing

• **Monitor** aspects of environment that affect fitness (survive & reproduce)

• Three steps:
  • (1) a receptor cell receives an **external** signal
  • (2) the receptor cell sends a **signal to cells** in another part of the plant
  • (3) responder cells receive the signal and **change activity** appropriately.
1. Receptor cell perceives external stimulus and transduces the information to an internal signal.

2. A hormone (cell-cell signal) released by the receptor cell travels throughout the body.

3. Receptor cells receive the hormonal (cell-cell) signal, transduce it to an internal signal, and change activity.
Signal Transduction

• Signals from environment received by specialized protein (for that function).

• Receptor proteins change shape in response to a stimulus. This causes the information to change form—from an external signal to an intracellular signal.

• This process is called ________.
1. Signal

2. Receptor protein changes in response to signal.

3. Receptor or associated protein catalyzes phosphorylation reaction.

4. Phosphorylated protein triggers phosphorylation cascade (left)...

...OR release of second messenger (right).

5. Phosphorylated proteins or second messenger initiate response.

6. Activate or repress transcription.

OR

6. Activate or repress translation.

6. Change ion flow through channel or pump.
• Two basic signal transduction pathways:

• **Phosphorylation cascades** are triggered when the receptor protein's shape leads to the transfer of a phosphate group from ATP to the receptor or a nearby protein.

• **Second messengers** are produced when hormone binding results in the release of an intracellular signal (usually Ca\(^{2+}\) in plants) from storage areas.
Signal transduction in a receptor cell often results in the release of a _______ that carries information to responder cells.
Blue Light: The Phototropic Response

• Plants sense and respond to specific, narrow range of wavelengths
• Any directed movement by an organism toward light is called

• Plants exhibit a phototropic response only to blue wavelengths

• Why blue light?
Photosynthesis

Chlorophyll $a$ and $b$ Absorb Most Strongly in the Blue (and Red) Parts of the Visible Spectrum

Different pigments absorb different wavelengths of light
Shoots Bend Specifically toward Blue Light

(b) Shoots bend specifically toward blue light.
Auxin: Phototropic Hormone

• The sensory and response cells in phototropism are not the same. Blue light is sensed at the tip of a coleoptile (protected shoot) and info is then transmitted to lower cells.

• Auxin (a hormone) is produced at the tip of the coleoptile, is transported to the area of bending, and acts as a signal...

• Auxin promotes cell ________ in the shoot.
The Sensory and Response Cells Involved in Phototropism Are the Same
(a) The phototropic signal is a chemical. 

Light 

Permeable agar: 
Shoot bends toward light 

Impermeable mica: 
No bending 

Chemical diffuses through agar 

(b) The hormone can cause bending in darkness. 

Allow time for hormone to diffuse into agar block. 

Offset blocks cause bending of shoots not exposed to light 

(c) The hormone causes bending by elongating cells. 

Cells on the shaded side elongate in response to the hormone (red dots) 

Auxin moves from the light and then down
Photoperiodism & Flowering

- Flowering in response to changes in day length—triggered by red/far-red light.

- **Photoperiodism** is any response by an organism that is based on **photoperiod**, the relative lengths of day and night.

- In plants, the ability to measure photoperiod is important because it allows the plant to respond to seasonal changes in climate and the correlated availability of resources and pollinators.
Different Species Respond to Photoperiod in Different Ways

How do plants respond to differences in day length?

<table>
<thead>
<tr>
<th>Hours</th>
<th>Long-day (short-night) plant</th>
<th>Short-day (long-night) plant</th>
<th>Day-neutral (night-neutral) plant</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>Long day</td>
<td>Short night</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
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<tr>
<td>24</td>
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</tr>
</tbody>
</table>

(a)
Gravity: The Gravitropic Response

is the ability of plants to move in response to gravity. Roots grow down and shoots grow up or out.
Auxin as the Gravitropic Signal

- Root cap cells that sense changes in the direction of gravitational pull respond by changing the distribution of auxin in the root tip.
The Auxin Redistribution Hypothesis for Gravitropism
How Do Plants Respond to Wind and Touch?

• Plants get shorter and stockier in response to wind and touch.

• Thigmotropism is plant movement in response to touch.

• Recall Phenotypic Plasticity
Youth, Maturity, and Aging: The Growth Responses

• Controlling growth in response to changes in age or environmental conditions (one of the most basic aspects of information processing in plants).

• **Hormones** play a key role in regulating **______**.
Auxin and Apical Dominance

• **Apical dominance**: most of a stem's growth occurs at the shoot apical meristem.

• Apical dominance occurs because a __________ auxin from the tips of growing shoots to the tissues below signals the direction of growth.

• **If the signal stops**, it means that apical growth has been interrupted. In response, lateral buds sprout at the angles between leaves and the stem and begin to take over for the main shoot.
Auxin's Overall Role

• Auxin: controls growth via phototropism, gravitropism, and apical dominance.

• Auxin has other important effects as well:

• Fruit development is influenced by auxin produced by seeds within the fruit.

• Falling auxin concentrations are involved in _______ (the shedding of leaves and fruits) associated with _________ aging.
Cytokinins & Cell Division

- Cytokinins are a group of plant hormones that promote cell division.

- Cytokinins are synthesized in root tips, young fruits, seeds, growing buds, and other developing organs.

- Cytokinins regulate growth by _________ the _____ that keep the cell cycle going. In the absence of cytokinins, cells arrest at the $G_1$ checkpoint in the cell cycle and cease growth.
Cytokinins Affect the Cell Cycle

Cytokinins promote expression of genes that start S phase (DNA synthesis). Without cytokinins, cells remain in G₁ and do not divide.
Gibberellins and ABA: Growth and Dormancy

• Two types of hormones are responsible for initiating and terminating growth in plants in response to changes in environmental conditions:

• **gibberellins** _______ growth, abscisic acid (ABA) _______ growth.
Gibberellins Stimulate Shoot Elongation

• Gibberellic acid (GA) is a gibberellin that appears to promote cell elongation and to increase rates of cell division in roots.
Gibberellins and ABA Interact during Seed Dormancy and Germination

• Many plants produce seeds that have to undergo a period of drying or a period of cold, wet conditions before they are able to germinate in response to warm, wet conditions.

• In many plants, ABA is the signal that inhibits seed germination, and gibberellins are the signal that triggers embryonic development.
Video 34.3 Germination of soybean plants
• During seed germination, gibberellins activate production of \( \alpha \)-amylase, a digestive enzyme that breaks the bonds between sugar units of starch. This releases sugars to the growing embryo.
ABA Closes Guard Cells in Stomata

• In most plants, stomata open in response to blue light, allowing gas exchange during photosynthesis. When stomata are open, water can be lost; if the roots cannot replace water lost at the leaves, then the stomata close.

• ABA from ________ is transported to leaves, resulting in the ________ Therefore, this signal overrides that from the blue-light receptors.
Ethylene and Senescence

- **Senescence** = regulated aging process.

- The gaseous hormone **ethylene** is strongly associated with three aspects of senescence in plants:
  - 1) _______
  - 2) flower fading
  - 3) abscission.
The **abscission zone** is a region of the leaf petiole that becomes more sensitive to ethylene as auxin levels drop. As a result, it degrades first and the leaf breaks off at this point.
Leaves Drop in Response to Signals from Auxin and Ethylene

LEAF SENESCENCE AND ABSCISSION

Healthy leaf

1. High auxin: Cells in abscission zone are insensitive to ethylene. Leaf functions normally.

Senescent leaf

2. Low auxin: Cells in abscission zone become more sensitive to ethylene, leading to leaf senescence.

Abscised leaf

3. Leaf detaches at the abscission zone.

Age, drought, temperature, day length, etc. reduce auxin production from leaf.

A protective layer has formed to seal stem where leaf was attached.
Overview

Plant Growth Regulators

(1) A single hormone often affects many different target tissues. This means there can be an array of responses to the same cell-cell signal.

(2) In most cases, several hormones affect the same response.

Hormones do not work independently—they _______ with each other.
How Do Plants Sense and Respond to Pathogens?

• If a pathogen invades a plant, the plant mounts a defense called the hypersensitive response (HR). HR causes the rapid and localized death of cells surrounding the site of infection.

• Other Responses too...
Video 39.1
Lepidopteran larvae feeding on leaves
Herbivory

= toxins

(Primary metabolites involved in homeostasis and typical cellular function)

- Tobacco makes nicotine
  - Harmful to many herbivores
Secondary Metabolites

• **Hormones/Pheromones**
  - *Mimic* juvenile hormone; stop molt to adult
  - *Attract* your herbivore’s insect prey!
  - *Warn* other plants to mobilize their defensive cascades

• **Poisons**
  - *Disrupt* nervous system of herbivore
    - nicotine
  - *Disrupt* digestive system of herbivore
    - proteinase inhibitors
How Do Plants Sense and Respond to Herbivore Attack?

• Many plant seeds and storage organs contain **proteinase inhibitors**, proteins that block the enzymes found in the mouths and stomachs of animals that digest proteins.

• When a herbivore ingests a large dose of a proteinase inhibitor, it gets sick. As a result, **herbivores learn** to detect and avoid plant tissues containing high concentrations of these proteins.
Pheromones Released from Plant Wounds Recruit Help from Wasps

• A **parasitoid** is an organism that is free living as an adult but parasitic as a larva. Because parasitoids (for example, a wasp egg laid in a caterpillar's body) kill their host, *parasitoid* attacks limit the amount of damage that *herbivores* do to plants.

• **Pheromones** are chemical messengers synthesized by an individual and released into the environment that elicit a response from a different individual.

• **Plants produce wasp attractant pheromones** in response to attack by caterpillars.
Parasitoid wasp
HYPOTHESIS: Corn roots attacked by beetle larvae attract nematodes that will attack the larvae.

Attract the herbivore’s prey!

CONCLUSION: The nematodes were attracted to the roots that had been attacked by the beetle larvae.
# Secondary Metabolites

## Table 39.1

<table>
<thead>
<tr>
<th>CLASS</th>
<th>TYPE</th>
<th>ROLE</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen-containing</td>
<td>Alkaloids</td>
<td>Affect herbivore nervous system</td>
<td>Nicotine in tobacco</td>
</tr>
<tr>
<td></td>
<td>Glycosides</td>
<td>Release cyanide or sulfur compounds</td>
<td>Dhurrin in sorghum</td>
</tr>
<tr>
<td></td>
<td>Nonprotein amino acids</td>
<td>Disrupt herbivore protein structure</td>
<td>Canavanine in jack bean</td>
</tr>
<tr>
<td>Phenolics</td>
<td>Flavonoids</td>
<td>Phytoalexins</td>
<td>Capsidol in peppers</td>
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<tr>
<td></td>
<td>Quinones</td>
<td>Inhibit competing plants</td>
<td>Juglone in walnut</td>
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<tr>
<td></td>
<td>Tannins</td>
<td>Deter herbivores and microbes</td>
<td>Many woods, such as oak</td>
</tr>
<tr>
<td>Terpenes</td>
<td>Monoterpenes</td>
<td>Insecticides</td>
<td>Pyrethroids in chrysanthemums</td>
</tr>
<tr>
<td></td>
<td>Sesquiterpenes</td>
<td>Phytoalexins; deter herbivores</td>
<td>Gossypol in cotton</td>
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<tr>
<td></td>
<td>Steroids</td>
<td>Mimic insect hormones and disrupt insect life cycles</td>
<td>$\alpha$-Ecdysone in ferns</td>
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<tr>
<td></td>
<td>Polytterpenes</td>
<td>Feeding deterrent?</td>
<td>Latex in rubber tree</td>
</tr>
</tbody>
</table>
grapes/wine

Tannins

oak leaves
Milkweeds

Secrete a poisonous latex
Swallowtail butterflies incorporate milkweed toxins into their own tissues for defense (via bird learning)
Milkweeds

Secrete a poisonous latex

Some herbivores ‘learn’ to disable the defense (cut the latex supply lines, then eat the leaf!)

Another example of an evolutionary ‘arms race’
Cyanide (CN)

Cyanide is a very rapidly acting toxin (used by communes for suicide!).

In plants, CN is combined with sugar as a cyanogenic glycoside.

Precursors, stored in vacuoles, get together in cytosol if plant is damaged by wilting, crushing, or chewing.

More than 1000 plant species have cyanide in some form.
Aspirin!

• **Salicylic Acid** common in plants
  - Well-studied in Willows (*Salix*)
  - Used to combat many pathogens
    - (e.g., viruses)

• **Methyl salicylate**, a related compound
  - aka ‘oil of wintergreen’
  - Volatilizes to signal other plants (pheromone) to defend selves
The size of plant reproductive structures is highly variable.

(a) Small reproductive structures

(b) Small seeds

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Small reproductive structures

Large reproductive structures

Small seeds

Large seeds

Plant

Flower

Tip of sewing needle

1 mm

Penny

10 cm
Plant Reproduction

182 Bonine
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DECIDED TO SKIP B/C
MUCH OF THIS MATERIAL COVERED ALREADY
Video 34.1 Time-lapse of bud burst in plants