

CHAPTER 27 CONTROL OF GROWTH AND RESPONSES IN PLANTS

Chapter Outline

27.1 Plant Responses

- A. Organisms Respond to Stimuli
 1. One defining characteristic of life is an ability to respond to stimuli.
 2. Adaptive organisms respond to environmental stimuli because it leads to longevity and survival of the species.
 3. Animals have nerves and muscles; plants respond by growth patterns.
- B. Tropisms
 1. A **tropism** is plant growth toward or away from a **directional** stimulus.
 - a. The stimulus comes from only one direction instead of many.
 - b. Growth toward a stimulus is a **positive tropism**; growth away from a stimulus is a **negative tropism**.
 - c. By differential growth, one side elongates faster; the result is a curving toward or away from a stimulus.
 2. Three well-known tropisms are named for the stimulus that causes the response.
 - a. **Phototropism** is growth of plants in response to light; stems show positive phototropism.
 - b. **Gravitropism** is response to earth's gravity; roots demonstrate positive gravitropism and stems demonstrate negative gravitropism.
 - c. **Thigmotropism** is unequal growth due to touch (e.g., coiling of tendrils around a pole).
 3. Response to a stimulus first involves **reception** of the stimulus.
 4. The next step is **transduction** of the stimulus into a form meaningful to the organism.
 5. Finally, there is a **response** by the organism.
- C. Phototropism
 1. Early researchers, including Charles Darwin and his son Francis, observed plants curve toward light.
 2. Phototropism occurs because cells on shady side of stems elongate.
 3. It is believed that a yellow pigment related to riboflavin acts as a photoreceptor for light.
 - a. Following reception, the plant hormone **auxin** migrates from the bright side to the shady side of a stem.
 - b. How reception of stimulus couples to production of auxin is not yet known.
 4. Auxin is also involved in gravitropism, apical dominance, and root and seed development.
- D. Gravitropism
 1. An upright plant placed on its side displays **negative gravitropism**; it grows upward opposite gravity.
 2. Charles Darwin and his son were first to show that roots display **positive gravitropism**.
 - a. If the root cap is removed, roots no longer respond to gravity.
 - b. Later researchers showed root cap cells contain **statoliths**, starch grains within amyloplasts.
 - c. Due to gravity, amyloplasts settle to the lowest part of the cell.
 3. The hormone auxin underlies both positive and negative gravitropisms.
 - a. The two tissues respond differently to auxin, which moves to the lower side of both stems and root.
 - b. Auxin inhibits the growth of root cells; cells of the upper surface elongate and the root curves downward.
 - c. Auxin stimulates the growth of stem cells; cells of the lower surface elongate and the stem curves upward.
- E. Thigmotropism
 1. Unequal growth due to contact with solid objects is **thigmotropism**.
 2. The coiling of morning glory or pea tendrils around posts, etc., is a common example.
 3. Cells in contact with an object grow less while those on the opposite side elongate.
 4. This process is quite rapid; tendrils have been observed to encircle an object in ten minutes.
 5. A couple of minutes of stroking can bring about a response that lasts for several days.
 6. The response can be delayed; tendrils touched in the dark will respond when illuminated.
 - a. ATP rather than light can cause the response; the need for light is simply a need for ATP.

- b. The hormones auxin and ethylene are involved; they induce curvature of tendrils in the absence of touch.
 - 7. Thigmomorphogenesis is a touch response involving the whole plant.
 - a. An entire plant responds to presence of wind or rain.
 - b. A plant growing in a windy location has a shorter, thicker trunk.
 - c. Simple rubbing of a plant inhibits cellular elongation and produces a shorter, sturdier plant.
- F. Nastic Movements
 - 1. In contrast to tropisms, **nastic movements** are independent of the direction of stimulus.
 - 2. **Seismonastic movements** result from touch, shaking, or thermal stimulation.
 - 3. When a *Mimosa pudica* leaf is touched, the leaflets fold because the petiole droops.
 - 4. This response takes only a second or two and is due to a loss of turgor pressure within cells.
 - 5. A **pulvinus** is a thickening at base of such leaflets where turgor pressure can rapidly drop.
 - 6. Potassium ions move out of the cell and water follows by osmosis.
 - 7. A single stimulus such as a hot needle can cause all of the leaves to respond; this requires a nerve impulse-like stimulus for communication.
 - 8. Venus's-flytrap
 - a. This plant has three sensitive hairs at the base of the trap.
 - b. When touched by an insect, an impulse-type stimulus triggers the trap to close.
 - c. Turgor pressure in leaf cells then propel the trap.
- G. Sleep Movements
 - 1. **Sleep movements** are nastic responses to the daily changes in light level; an example is the prayer plant that folds its leaves each night.
 - 2. Movement is due to changes in turgor pressure of motor cells in a pulvinus.
 - 3. Some plant movements correspond to environmental changes in light, temperature, etc.
 - 4. **Circadian rhythms** are biological rhythms with a 24-hour cycle.
 - 5. A **biological clock** is an internal mechanism maintaining biological rhythms in absence of stimuli.
 - 6. Biological clocks are synchronized by external stimuli to twenty-four-hour rhythms.
 - 7. Photoperiod is more reliable an indicator of seasonal changes than temperature change.
 - 8. Stomata and flowers usually open in the morning, close at night; some plants secrete nectar at same time of day.

27.2 Plant Hormones

- A. For plants to respond to stimuli, activities of plant cells and structures have to be coordinated.
 - 1. Almost all plant communication is done by **hormones**.
 - 2. **Hormones** are low concentration chemical messengers that are active in another part of the organism.
 - 3. A response is influenced by several hormones and may require a specific ratio of two or more hormones.
 - 4. Hormones are synthesized in one part of a plant; they travel in the phloem after a plant receives an appropriate stimulus.
 - 5. Each naturally-occurring hormone has a specific chemical structure.
 - 6. Other chemicals that differ only slightly from natural hormones also affect the growth of plants.
 - 7. **Plant growth regulators** are hormone imitators plus naturally-occurring plant growth hormones.
- B. Affects of Auxins
 - 1. Auxin is produced in shoot apical meristem and found in young leaves, flowers, and fruits.
 - a. When a terminal bud is removed, the nearest buds begin to grow and the plant branches.
 - b. Application of a weak solution of auxin causes roots to develop from the ends of cuttings.
 - c. Auxin production by seeds promotes growth of fruit.
 - d. As long as auxin is concentrated in leaves and fruits rather than stem, they do not fall off.
 - 2. Auxin-controlled cell elongation is involved in gravitropism and phototropism.
 - a. When gravity is perceived, auxin moves to lower surface of roots and stems.
 - b. Darwin discovered with oat seedlings, phototropism would not occur if the tip of a seedling is cut off or covered by a cap; they concluded the cause of curvature moved from coleoptile tip to the rest of the shoot.

3. Frits W. Went experimented with coleoptiles in 1926.
 - a. He cut off tips and placed them on agar.
 - b. When an agar block was placed to one side, the coleoptile would curve away from that side regardless of the light.
 - c. He deduced a chemical caused the curved growth and he named it auxin after the Greek word for “to grow.”
- C. How Auxins Work
1. In a plant exposed to unidirectional light, auxin moves from the bright side to the shady side of a stem.
 2. Auxin binds to receptors and activates the ATP-driven proton (H^+) pump.
 3. As hydrogen ions are pumped out of the cell, the cell wall becomes acidic, breaking hydrogen bonds.
 4. Cellulose fibrils are weakened and activated enzymes further degrade the cell wall.
 5. The electrochemical gradient established causes uptake of solutes and water follows by osmosis.
 6. The turgid cell presses against the cell wall, stretching it so that elongation occurs.
 7. Auxin-mediated elongation occurs in younger cells; older cells may lack auxin receptors.
- D. Gibberellins
1. Gibberellins are a group of 70 plant hormones that chemically differ only slightly.
 2. **GA₃** is the most common of the natural gibberellins.
 3. **Gibberellins** are growth promoters that elongate cells.
 4. Gibberellins were discovered in 1926 by Ewiti Kurosawa, a Japanese scientist investigating a fungal disease of rice plants called “foolish seedling disease.”
 - a. His fungus-infected plants produced an excess chemical gibberellin, named after the fungus.
 - b. By 1956, gibberellic acid was finally isolated from a flowering plant rather than fungus.
 5. Mode of action
 - a. The hormone GA₃ binds to a receptor; a second messenger (Ca^{2+}) inside cell combines with the protein **calmodulin**.
 - b. The Ca^{2+} -calmodulin complex activates a gene coding for the enzyme amylase.
 - c. Amylase acts on starch to release sugars used as a source of energy by the growing embryo.
- E. Cytokinins
1. **Cytokinins** are a class of plant hormones that promote cell division.
 2. Cytokinins are derivatives of the purine base adenine.
 3. A natural cytokinin **zeatin** is found in corn kernels; kinetin is a synthetic cytokinin.
 4. Researchers discovered cytokinins in work on growing plant tissues in culture.
 5. **Oligosaccharins**, chemical fragments released from cell wall, also direct differentiation.
 6. Researchers hypothesize that auxin and cytokinins are part of a reception-transduction-response pathway that activates enzymes that release these fragments from the cell wall.
- F. Senescence
1. Aging processes are **senescence**; large molecules break down and are transported elsewhere in the plant.
 2. Cytokinins prevent senescence of leaves; they also initiate development of leaf growth.
 3. Cytokinins initiate growth of lateral buds despite apical dominance.
- G. Abscisic Acid
1. **Abscisic acid (ABA)** is sometimes called the “stress hormone”; it maintains seed and bud **dormancy** and causes closure of stomata.
 2. **Dormancy** occurs when a plant organ readies itself for adverse conditions by stopping growth.
 - a. ABA moves from leaves to vegetative buds in fall; thereafter these buds are converted to winter buds which are covered by thick, hardened scales.
 - b. Reduction in ABA and increase in gibberellins break seed and bud dormancy; seeds germinate and buds send forth leaves.
 3. Abscisic acid brings about closing of stomata when a plant is under water stress.
 - a. By some unknown mechanism, ABA causes K^+ ions to leave guard cells.
 - b. As a result, guard cells lose water and the stomata close.
 4. Although external application of ABA promotes abscission, it is not believed to function in this process; the hormone ethylene is considered to have this natural function.

H. Ethylene

1. Ethylene is involved in **abscission**, the dropping of leaves, fruits, or flowers.
 - a. Lower levels of auxin in these areas (compared to stem) probably initiate abscission.
 - b. Once abscission begins, ethylene stimulates production of enzymes such as cellulase that cause leaf, fruit, or flower drop.
2. It was an early practice to prepare citrus fruit for market by storage in a room with a kerosene stove.
3. Later work revealed incomplete combustion of kerosene produced ethylene which ripens fruit.
4. **Ethylene** is a gaseous plant hormone; it ripens fruit by increasing the activity of enzymes that soften fruit.
5. Ethylene stimulates production of a **cellulase** enzyme that hydrolyzes cellulose in plant cell walls.
6. A barrel of ripening apples can induce ripening of a bunch of bananas some distance away.
7. Ethylene releases from site of a physical wound; therefore one rotten apple spoils the whole bunch.
8. The presence of ethylene in air inhibits growth of plants in general.
9. Ethylene is present in auto exhaust and in homes heated with natural gas.
10. Inhibition of plant growth occurs in low concentrations (one part ethylene per 10 million parts of air).

27.3 Photoperiodism

- A. Many physiological changes in plants (e.g., seed germination, the breaking of bud dormancy, and the onset of senescence) are related to a seasonal change in day length.
 1. **Photoperiodism** is a physiological response to relative lengths of daylight and darkness.
 2. Research by U.S. Department of Agriculture in the 1920s in controlled greenhouses revealed this mechanism.
 3. In some plants, photoperiodism also affects flowering.
- B. Plants can be divided into three groups, based on photoperiodism.
 1. **Short-day Plants**
 - a. These plants flower when day length was shorter than a critical length.
 - b. Examples include cocklebur, poinsettia, and chrysanthemum.
 - c. In effect, they require a period of darkness that is longer than a critical length to flower.
 2. **Long-day Plants**
 - a. These plants flower when the day length is longer than a critical length.
 - b. Examples include wheat, barley, clover, and spinach.
 - c. In effect, they require a period of darkness that is shorter than a critical length to flower.
 3. **Day-neutral Plants**
 - a. These are plants for which flowering is not dependent on day length.
 - b. Examples include tomato and cucumber.
- C. A long-day and a short-day plant can have the same critical length.
 1. These plants differ in specific sequence of day lengths as a season progresses.
 2. Spinach is a long-day plant that flowers in summer when day length increases to 14 hours.
 3. Ragweed is a short-day plant that flowers in fall when day length shortens to 14 hours or less.
 4. In 1938, K. C. Hammer and J. Bonner experimented with artificial lengths of dark and light periods.
 - a. Cocklebur, a short-day plant, flowers as long as the dark period lasts over 8.5 hours.
 - b. If the dark period is interrupted by a flash, it does not flower; but darkness amidst a day cycle has no effect.
 - c. Long-day plants require a dark period shorter than a critical length regardless of the length of the light period.
 - d. Therefore, length of the dark period controls flowering, not length of the light period.
- D. Phytochrome and Plant Flowering
 1. U.S.D.A. scientists discovered **phytochrome**, a blue-green leaf pigment that exists in two forms.
 2. P_r (phytochrome red) absorbs red light (wavelength of 660 nm); it is converted to P_{fr} .
 3. P_{fr} is phytochrome far-red and absorbs far-red light (wavelength of 730 nm); it is converted to P_r .
 4. During a 24-hour period, there is a shift in ratio of these two pigments.
 - a. Direct sunlight contains more red than far-red light; P_{fr} is present in plant leaves during the day.
 - b. Shade and sunsets have more far-red than red light; P_{fr} is converted to P_r as night approaches.
 - c. There is a slow metabolic replacement of P_{fr} by P_r during night.
 5. Phytochrome conversion may be a first step in reception-transduction-response pathway resulting in flowering.

E. Other Functions of Phytochrome

1. The $P_r \rightarrow P_{fr}$ conversion cycle controls other growth functions in plants.
2. In addition to being involved in flowering, P_{fr} promotes seed germination and inhibits stem elongation.
3. Following germination, the presence of P_r dominates; the stem elongates and grows toward sunlight while the leaves remain small.
4. Once a plant is exposed to sunlight and P_r is converted to P_{fr} , the plant begins to grow normally—leaves expand and the stem branches.
5. The P_{fr} form of phytochrome triggers activation of one or more regulatory proteins in the cytosol.
6. These proteins migrate to the nucleus and bind to “light-stimulated” genes coding for proteins found in chloroplasts.