

Chapter 39: Plant Responses to Internal and External Signals

1. What causes a shriveled potato to grow skinny, pale sprouts?

Morphological adaptations for growing in darkness, collectively referred to as etiolation, make sense if we consider that a young potato plant in nature usually encounters continuous darkness when sprouting underground. Under these circumstances, expanded leaves would be a hindrance to soil penetration and would be damaged as the shoots pushed through the soil. Because the leaves are unexpanded and underground, there is little evaporative loss of water and little requirement for an extensive root system to replace the water lost by transpiration. Moreover, the energy expended in producing green chlorophyll would be wasted in the absence of light. Instead, a potato plant growing in the dark allocates as much energy as possible to elongating its stems. This adaptation enables the shoots to break ground before the nutrient reserves in the tuber are exhausted.

2. What causes the sprouts to form short, sturdy stems and broad, green leaves when the potato is exposed to light?

When a shoot reaches light, the plant undergoes profound changes, collectively called de-etiolation (informally known as greening). Stem elongation slows; leaves expand; roots elongate; and the shoot produces chlorophyll.

4. Explain how the light signal causes the greening response.

Signals are first detected by receptors, proteins that undergo changes in shape in response to a specific stimulus. The receptor involved in de-etiolation is a type of phytochrome, a member of a class of photoreceptors that we'll discuss more fully later in the chapter. Unlike most receptors, which are built into the plasma membrane, the type of phytochrome that functions in de-etiolation is located in the cytoplasm. Receptors can be sensitive to very weak environmental or chemical signals.

5. What are the two second messengers in this pathway?

The transduction of extremely weak signals involves second messengers – small molecules and ions in the cell that amplify the signal and transfer it from the receptor to other proteins that carry out the response. Calcium ions (Ca^{2+}) and cyclic GMP (cGMP) are the second messengers involved in de-etiolation.

6. Both plants and animals have hormones. What are they?

A hormone, in the original meaning of the term, is a signaling molecule that is produced in tiny amounts by one part of an organism's body and transported to other parts, where it binds to a specific receptor and triggers responses in target cells and tissues. In animals, hormones are usually transported through the circulatory system, a criterion often included in definitions of the term.

7. What term do plant physiologists use instead of "hormone"?

Plants don't have circulating blood to transport hormone-like signaling molecules. Moreover, some signaling molecules that are considered plant hormones act only locally. Finally, there are some signaling molecules in plants, such as sucrose, that typically occur in plants at concentrations that are hundreds of thousands times greater than a typical hormone. Nonetheless, they are transported through plants and activate signal transduction pathways that greatly alter the functioning of plants in a manner similar to a hormone. Thus, many plant biologists prefer the broader term "plant growth regulator" to describe organic compounds, either natural or synthetic, that modify or control one or more specific physiological processes within a plant.

8. What is a tropism?

Any growth response that results in plant organs curving toward or away from stimuli is called a tropism. The growth of a shoot toward light or away from it is called phototropism; the former is positive phototropism, and the latter is negative phototropism.

9. What can be concluded from Charles and Francis Darwin's early experiments on phototropism?

The Darwins' experiment suggested that only the tip of the coleoptile senses light. The phototropic bending, however, occurred at a distance from the site of light perception (the tip).

10. What conclusions can be drawn from the Boysen-Jensen experiment?

Boysen-Jensen's results suggested that the signal for phototropic bending is a light-activated mobile chemical.

11. Explain the results of Fritz Went's modified experiment building on Boysen-Jensen's work.

Went concluded that a coleoptile curves toward light because its dark side has a higher concentration of the growth-promoting chemical, which he named auxin.

12. What name did Went give to this chemical messenger? What was its chemical structure found to be?

The major type of auxin was later purified, and its chemical structure was determined to be indoleacetic acid (IAA).

13. List and describe four functions of auxin.

Auxin Functions	Description
stimulates elongation of cells within young developing shoots	stimulates cell growth by binding to a receptor in the plasma membrane; may inhibit cell elongation at higher concentration; proton pumps play a major role according to the acid growth hypothesis; increased turgor and increased cell wall plasticity enable the cell to elongate
rapidly alters gene expression	causes cells in the region of elongation to produce new proteins within minutes; stimulates sustained growth response
pattern formation	carries integrated information about the development, size, and environment of individual branches; flow of information controls branching patterns; directs patterns of leaf veins; controls activity of vascular cambium, the meristem that produces woody tissues
key role in phyllotaxy	arrangement of leaves on the stem

14. Explain how herbicides kill dandelions without killing the grass.

Certain synthetic auxins are widely used as herbicides. Monocots, such as maize and turfgrass, can rapidly inactivate such synthetic auxins. However, eudicots cannot and therefore die from hormonal overdose.

15. How did cytokinins get their name?

Growth regulators were named cytokinins because they stimulate cytokinesis, or cell division.

16. List and describe three functions of cytokinins.

Cytokinin Functions	Description
cell division; cell differentiation	stimulate cell division and influence the pathway of differentiation in concert with auxin; ratio of cytokinins to auxin controls cell differentiation in callus; shoot buds form if cytokinin levels increase; roots form if auxin levels increase
apical dominance	ability of apical bud to suppress the development of axillary buds
anti-aging effects	slow the aging of certain plant organs by inhibiting protein breakdown, stimulating RNA and protein synthesis, and mobilizing nutrients from surrounding tissues; slow the progress of apoptosis

17. Describe three effects of gibberellins.

Gibberellin Functions	Description
stem elongation	stimulate stem and leaf growth by enhancing cell elongation and cell division; bolting (rapid growth of the floral stalk)
fruit growth	in many plants, both auxin and gibberellins must be present for fruit to develop
germination	after water is imbibed, release of gibberellins from embryo signals seed to break dormancy and germinate

18. Why is abscisic acid (ABA) misnamed?

Ironically, ABA is no longer thought to play a primary role in bud dormancy or leaf abscission.

19. Describe three effects of abscisic acid.

<i>Absciscic Acid Functions</i>	<i>Description</i>
seed dormancy	increases the likelihood that seeds will germinate only when there are sufficient amounts of light, temperature, and moisture for the seedlings to survive; inhibit germination and induce production of proteins that help the seeds withstand the extreme dehydration that accompanies maturation
drought tolerance	accumulates in the leaves and causes stomata to close rapidly, reducing transpiration and preventing further water loss; causes potassium channels in the plasma membrane of guard cells to open, leading to a massive loss of potassium ions from the cells; accompanying osmotic loss of water reduces guard cell turgor, leads to closing of stomatal pores
early warning system	water shortage stresses the root system before the shoot system; ABA transported from roots to leaves "early warning"

20. Ethylene is the only hormone in our group that is a gas. Under what conditions is ethylene produced?

Plants produce ethylene in response to stresses such as drought, flooding, mechanical pressure, injury, and infection. Ethylene is also produced during fruit ripening, programmed cell death and in response to high concentrations of externally applied auxin.

21. Describe the effects of ethylene.

<i>Ethylene Functions</i>	<i>Description</i>
triple response to mechanical stress	triple response: growth maneuver enables shoot to avoid an obstacle; involves slowing of stem elongation, thickening of the stem, and curvature that causes the stem to start growing horizontally
senescence	programmed death of certain cells or organs or the entire plant; involves apoptosis, requiring gene expression; plant salvages many breakdown products
leaf abscission	loss of leaves from deciduous trees; helps prevent desiccation during seasonal periods of climatic stress that severely limit the availability of water to the roots; essential elements of leaves salvaged before abscission; change in ratio of ethylene to auxin controls abscission
fruit ripening	ethylene triggers ripening, which triggers more ethylene production; signal to ripen spreads from fruit to fruit

22. Summarize the actions of various plant hormones.

<i>Hormone</i>	<i>Action</i>
ethylene	leaf abscission
abscisic acid	breaking seed dormancy
cytokinins	maintaining apical dominance
gibberellin	making internodes of grape bunches elongate to obtain larger fruit
auxin	gravitropism
abscisic acid	drought tolerance
ethylene	senescence
auxin	phototropism
auxin	cell elongation
cytokinins	increased cell division

23. What are the two major classes of light receptors in plants?

Red and blue light are the most important colors in regulating a plant's photomorphogenesis. The two major classes of light receptors are blue-light photoreceptors and phytochromes, which absorb mostly red light.

24. What wavelengths of light are absorbed by phytochromes?

A phytochrome has two identical subunits, each containing a chromophore, the light-absorbing part of the subunit. The chromophore of a phytochrome is photoreversible, reverting back and forth between two isomeric forms, depending on

the color of light provided. In its P_r isomer form, a phytochrome absorbs red light maximally, whereas in its P_{fr} isomer form, it absorbs far-red light.

26. *What are the wavelengths of red light and far-red light?*

Red light has a wavelength of ~660 nm. Far-red light has a wavelength of ~730 nm.

28. *What is the active form of phytochrome, P_r or P_{fr} ?*

Plants synthesize phytochrome as P_r . P_{fr} is the active form of phytochrome.

29. *What determines the lettuce seed's response to light exposure?*

When lettuce seeds are subjected to a flash of red light followed by a flash of far-red light or vice versa, the last flash of light determines the seeds' response: the effects of red and far-red light are reversible. Plants synthesize phytochrome as P_r , and if lettuce seeds are kept in the dark, the pigment remains almost entirely in the P_r form. Sunlight contains both red and far-red light, but the conversion to P_{fr} is faster than the conversion to P_r . Therefore the ratio of P_{fr} to P_r increases in the sunlight. When seeds are exposed to adequate sunlight, the production and accumulation of P_{fr} will trigger their germination.

30. *Which type of red light is more common in a shaded area and why?*

If a tree is shaded by other trees in a forest, the phytochrome ratio shifts in favor of P_r because the forest canopy screens out more red light than far-red light.

31. *What is a circadian rhythm? Give one plant example and one human example.*

Circadian rhythms are cycles with a frequency of about 24 hours and not controlled by any known environmental variable according to which many plant processes, such as transpiration and the synthesis of certain enzymes, undergo a daily oscillation. For example, many legumes lower their leaves in the evening and raise them in the morning. *Homo sapiens sapiens* are awake by day and sleep at night, while the reverse is true of *Homo sapiens juvenis*.

32. *What is the photoperiod?*

Seasonal events are of critical importance in the life cycles of most plants. The environmental stimulus that plants use most often to detect the time of year is the photoperiod, the relative lengths of night and day. A physiological response to photoperiod, such as flowering, is called photoperiodism.

33. *Explain short-day plants, long-day plants, and day-neutral plants, and give an example of a plant in each group.*

Short-day plants such as chrysanthemums and poinsettias require a light period shorter than a critical length to flower. Long-day plants such as radishes, lettuce, and irises, which flower only when the light period is longer than a certain number of hours, generally flower in late spring or early summer. Day-neutral plants such as tomatoes, rice, and dandelions, are unaffected by photoperiod and flower when they reach a certain stage of maturity, regardless of day length.

35. *What is florigen?*

Florigen is the hypothetical signaling molecule for flowering, which now appears to be a macromolecule. A gene called Flowering Locus T (FT) is activated in leaf cells during conditions favoring flowering, and the FT protein travels through the symplasm to the shoot apical meristem and initiates flowering.

41. *What are the two ways in which plants combat excess herbivory?*

Plants maintain both physical defenses, such as thorns and trichomes, and chemical defenses, such as the production of distasteful or toxic compounds.

42. *Describe two examples of a plant producing chemicals to deal with herbivory.*

Some plants produce canavanine, an unusual amino acid that resembles arginine. If an insect eats a plant containing canavanine, the molecule is incorporated into the insect's proteins in place of arginine. Because canavanine is different enough from arginine to adversely affect the shape and hence the function of the proteins, the insect dies. Some plants even "recruit" predatory animals that help defend the plant against specific herbivores, such as the maize leaf, which "recruits" parasitoid wasps as a defensive response to the herbivorous armyworm caterpillar.

Plant Hormones List

<i>Hormone</i>	<i>Where Found</i>	<i>Major Functions</i>
auxin (IAA)	shoot apical meristems and young leaves are the primary sites of auxin synthesis; root apical meristems also produce auxin, although the root depends on the shoot for much of its auxin; developing seeds and fruits contain high levels of auxin, but it is unclear whether it is newly synthesized or transported from maternal tissues	stimulates stem elongation (low concentration only); promotes the formation of lateral and adventitious roots; regulates development of fruit; enhances apical dominance; functions in phototropism and gravitropism; promotes vascular differentiation; retards leaf abscission
cytokinins	synthesized primarily in roots and transported to other organs; many minor sites of production	regulate cell division in shoots and roots; modify apical dominance; promote lateral bud growth; promote movement of nutrients into sink tissues; stimulate seed germination; delay leaf senescence
gibberellins	meristems of apical buds and roots, young leaves, and developing seeds are the primary sites of production	stimulate stem elongation, pollen development, pollen tube growth, fruit growth, seed development and germination; regulate sex determination and the transition from juvenile to adult phases
brassinosteroids	compounds present in all plant tissues, although different intermediates predominate in different organs; internally produced brassinosteroids act near the site of synthesis	promote cell expansion and cell division in shoots; promote root growth at low concentrations; inhibit root growth at high concentrations; promote xylem differentiation and inhibit phloem differentiation; promote seed germination and pollen tube elongation
abscisic acid (ABA)	almost all plant cells have ability to synthesize abscisic acid; its presence has been detected in every major organ and living tissue; may be transported in the phloem or xylem	inhibits growth; promotes stomatal closure during drought stress; promotes seed dormancy and inhibits early germination; promotes leaf senescence; promotes desiccation tolerance
strigolactones	carotenoid-derived hormones, extracellular signals produced in roots in response to low phosphate conditions or high auxin flow from the shoot	promote seed germination, control of apical dominance, and attraction of mycorrhizal fungi to the root
ethylene	gaseous hormone can be produced by most parts of the plant; produced in high concentrations during senescence, leaf abscission, and the ripening of some types of fruits; synthesis also stimulated by wounding and stress	promotes ripening of many types of fruit, leaf abscission, and triple response in seedlings (inhibition of stem elongation, promotion of lateral expansion, and horizontal growth); enhances rate of senescence; promotes root and root hair formation; promotes flowering in the pineapple family