Control Systems in Plants

- **Hormones** are ***chemical signals*** that are produced in one part of the body (plant), transported to other parts, bind to specific receptors, and trigger responses in targets cells and tissues.
  - Many plant responses, such as ***growth and development***, are controlled by the interaction of two or more hormones.
  - Specifically, hormones control plant growth and development by ***affecting the division, elongation, and differentiation of cells.***
- The concept of chemical messengers in plants came from a series of classic experiments on how stems respond to light.
  - Plants grow toward light, and if you rotate a plant, it will re-orient its growth until its leaves again face the light.
  - Any growth response that results in curvatures of whole plant organs toward or away from stimuli is called a **tropism**.
  - The growth of a shoot toward light is called positive **phototropism**.
- Much of what is known about **phototropism** has been learned from studies of grass seedlings.
  - Shoot of grass seedling enclosed in sheath called coleoptile
  - Grows straight up if kept in the dark
  - Curves toward light if illuminated from one side
  - Growth due to ***differential cell growth*** on **opposite** sides of the coleoptile
  - Cells on darker side elongate faster than cells on brighter side
  - ***Tip responsible for sensing light, however growth response occurs some distance below - signal transmitted from tip downward (Darwin)***

Auxins

- In 1926, F.W. Went extracted the chemical messenger for phototropism, naming it ***auxin***.
- Today, the term **auxin** is used for any chemical substance that promotes the elongation of coleoptiles, although auxins actually have multiple functions in flowering plants.
  - The natural auxin occurring in plants is indoleacetic acid, or IAA.
- Although auxin affects several aspects of plant development, one of its ***chief functions*** is to ***stimulate the elongation of cells in young shoots (primary growth)***.
  - The apical meristem of a shoot is a major site of auxin synthesis (where auxin is made).
- Auxin promotes phototropism.
  - As auxin moves from the apex down to the region of cell elongation, the hormone stimulates cell growth.
  - Auxin stimulates cell growth only over a certain concentration range (very low), from about 10^{-8} to 10^{-4} *M*.
  - At higher concentrations, auxins may inhibit cell elongation, probably by inducing production of ethylene, a hormone that generally acts as an inhibitor of elongation **(*we'll discuss this later*).**
- Auxins are used commercially in the vegetative propagation (asexual reproduction) of plants by cuttings.
  - Treating a detached leaf or stem with rooting powder containing auxin often causes adventitious roots to form near the cut surface.
  - Auxin is also involved in the branching of roots.
- Auxin also affects secondary growth *(adding girth to stems and roots)* by inducing cell division in the vascular cambium and by influencing the growth of secondary xylem.
- Developing seeds synthesize auxin, which promotes the growth of fruit.
  - Synthetic auxins sprayed on tomato vines induce development of seedless tomatoes because the synthetic auxins substitute for the auxin normally synthesized by the developing seeds.

Cytokinins

- **Cytokinins** stimulate cytokinesis, or cell division.
- Cytokinins are produced in actively growing tissues, ***particularly in roots, embryos, and fruits***.
  - Cytokinins produced in the root reach their target tissues by moving up the plant in the xylem sap.
- Cytokinins ***interact with auxins*** to stimulate ***cell division and differentiation.***
  - In the absence of cytokinins, a piece of parenchyma tissue grows large, but the cells do not divide.
  - In the presence of cytokinins and auxins, the cells divide.
  - If the ratio of cytokinins and auxins is balanced, then the mass of growing cells, called a callus, remains undifferentiated.
  - If cytokinin levels are raised, shoot buds form from the callus.
  - If auxin levels are raised, roots form.
- Cytokinins retard (slow) the aging of some plant organs.
  - They inhibit protein breakdown by stimulating RNA and protein synthesis, and by mobilizing nutrients from surrounding tissues.
  - Leaves removed from a plant and dipped in a cytokinin solution stay green much longer than otherwise.
  - Cytokinins also slow deterioration of leaves on intact plants.
  - Florists use cytokinin sprays to keep cut flowers fresh.

Gibberellins

- A century ago, farmers in Asia noticed that some rice seedlings grew so tall and spindly that they toppled over before they could mature and flower.
  - In 1926, E. Kurosawa discovered that a fungus in the genus *Gibberella* caused this “foolish seedling disease.”
  - The fungus caused hyper elongation of rice stems by secreting a chemical, given the name **gibberellin**.
- In the 1950s, researchers discovered that plants also make gibberellins and have identified more than 100 different natural gibberellins.
- ***Roots and leaves*** are major sites of gibberellin production.
  - Gibberellins stimulate growth in both leaves and stems but have little effect on root growth.
  - In stems, gibberellins ***stimulate cell elongation and cell division.***
- The effects of gibberellins in enhancing stem elongation are evident when certain dwarf varieties of plants are treated with gibberellins.
  - After treatment with gibberellins, dwarf pea plants grow to normal height.
  - However, if applied tonormal plants, there isoften no response, perhaps because these plants are already producing the optimal dose of the hormone.
- In many plants, both auxin and gibberellins must be present for fruit to set.
  - Spraying of gibberellin during fruit development is used to make the individual grapes grow larger and to make the internodes of the grape bunch elongate.
- The embryo of seeds is a rich source of gibberellins.

Abscisic acid (ABA)

- **Abscisic acid** (ABA) was discovered in the 1960s.
- ABA generally slows down growth.
- One major affect of ABA on plants is seed dormancy.
- ABA is the primary internal signal that enables plants to withstand drought.
  - When a plant begins to wilt, ABA accumulates in leaves and causes stomata to close rapidly, reducing transpiration and preventing further water loss.

Ethylene (unique, a gas)!

- In 1901, Dimitry Neljubow demonstrated that the gas **ethylene** was the active factor which caused leaves to drop from trees that were near leaking gas mains.
- Plants produce ethylene to cause leaf abscission (loss of leaves)
  - The loss of leaves each autumn is an adaptation that keeps deciduous trees from drying out during winter when roots cannot absorb water from the frozen ground.
- A change in the balance of ethylene and auxin controls abscission.
  - An aged leaf produces less and less auxin and this makes the cells of the abscission layer more sensitive to ethylene.
  - As the influence of ethylene continues, the cells in the abscission layer produce enzymes that digest the cellulose and other components of cell walls, eventually causing the leaf to drop.
- Ethylene production also occurs during fruit ripening.
- A chain reaction occurs during ripening: ethylene triggers ripening and ripening, in turn, triggers even more ethylene production - a rare example of positive feedback on physiology.
  - Because ethylene is a gas, the signal to ripen even spreads from fruit to fruit.
  - Fruits can be ripened quickly by storing the fruit in a plastic bag, accumulating ethylene gas or by enhancing ethylene levels in commercial production.
- Plants produce ethylene in response to stresses such as drought, flooding, mechanical pressure, injury, and infection.
- So, as you can see, plant hormones, such as auxin, cytokinin, gibberellin, ABA, and ethylene all have specific roles in plant growth and development.
- These plant hormones are components of control systems that tune a plant's growth, development, reproduction, and physiology to the environment.
  - For example, auxin functions in the phototropic bending of shoots toward light.
  - Abscisic acid “holds” certain seeds dormant until the environment is suitable for germination.
  - Ethylene functions in leaf abscission as shorter days and cooler temperatures announce autumn.

Plants and Light

- Light is an especially important factor on the lives of plants.
  - In addition to being required for photosynthesis, light also cues many key events in plant growth and development.
  - These effects of light on plant morphology are what plant biologists call **photomorphogenesis**.
  - Light reception is also important in allowing plants to measure the passage of days and seasons.
- Action spectra reveal that ***red and blue light*** are the most important colors regulating a plant's photomorphogenesis.
  - A family of photoreceptors (pigments) called ***phytochromes*** detect these light waves.
- Phytochromes were discovered from studies of seed germination.

Biological clocks control circadian rhythms in plants and other eukaryotes

- Many plant processes, such as transpiration and synthesis of certain enzymes, oscillate during the day.
  - This is often in response to changes in light levels, temperature, and relative humidity that accompany the 24-hour cycle of day and night.
  - Such physiological cycles with a frequency of about 24 hours and that are not directly paced by any known environmental variable are called **circadian rhythms**.
  - These rhythms are ubiquitous features of eukaryotic life.

Photoperiodism synchronizes many plant responses to changes of season

- The appropriate appearance of seasonal events are of critical importance in the life cycles of most plants.
  - These seasonal events include seed germination, flowering, and the onset and breaking of bud dormancy.
  - 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**.
- Based on photoperiodism, there are specific groups of plants:
- A **short-day plant**, requires a *shorter than average* light period length to flower.
  - Examples of short-day plants include chrysanthemums, poinsettias, and some soybean varieties.
- **Long-day plants** will only flower when the light period is *longer* than average.
  - Examples include spinach, iris, and many cereals.
- **Day-neutral plants** will flower when they reach a certain stage of maturity, regardless of day length.
  - Examples include tomatoes, rice, and dandelions.

- In the 1940s, researchers discovered that it is actually ***night length***, not day length, that controls flowering and other responses to photoperiod.
- Short-day plants are actually long-night plants, requiring a minimum length of uninterrupted darkness.
- Similarly, long-day plans are actually short-night plants.
- Long-day and short-day plants are distinguished *not* by an absolute night length but by whether the critical night lengths sets a maximum (long-day plants) or minimum (short-day plants) number of hours of darkness required for flowering.
  - In both cases, the actual number of hours in the critical night length is specific to each species of plant.
  - While the critical factor is night length, the terms "long-day" and "short-day" are embedded firmly in the jargon of plant physiology.

Tropisms orient plant growth toward or away from environmental stimuli

- Because of their immobility, plants must respond to environmental stimuli by developmental mechanisms.
- **Tropisms** are directed growth responses that cause parts of a plant to grow toward or away from a stimulus.
- Response to Gravity – ***GRAVITROPISM*** – shoot of a germinating plant will grow upward into the light and the root will grow into the soil, no matter how the seed lands or is planted in the soil.
- Response to Touch – ***THIGMOTROPISM*** – contact of a plant with objects encountered in their environment, has an effect on growth
  - Climbing plants have tendrils (modified leaves) that will coil and grasp rigid objects, using these objects for support while growing toward sunlight.