Control of Plant Growth and Development

The tree growing from a cliff shown in **Figure 1** seems to be defying gravity. However, its growth and development are, in fact, responding to gravity. It is vitally important for all plants to be able to grow in the correct orientation, so that the shoot grows toward sunlight and the roots grow down into the soil. In this section you will explore how plants can modify their development in response to the environment.

Figure 1 Despite being on a cliff, this tree still grows upward and its roots grow downward.

Plant Growth Regulators

The body shapes of plants can change as they grow and vary from individual to individual. Since plants cannot change location, this adaptation allows plants to respond to changes in the environment. For example, a plant grown in very low light looks dramatically different than one grown in full sunlight (**Figure 2**). In contrast, your body shape remains unchanged if you have had little exposure to light, although your health might suffer.

Plants are able to modify their growth and differentiation through the action of chemicals called **plant growth regulators**. In general, plant growth regulators act by signalling plant cells to undergo particular changes. Scientists have identified a number of plant growth regulators, and there may still be more. In this section you will explore five plant growth regulators that are found in most plants: auxins, gibberellins, cytokinins, ethylene, and abscisic acid.

Plant growth regulators have a number of effects on plant growth and differentiation. You will see that their effects depend on the type of tissue and the developmental stage of the plant. In addition, evidence shows that plant growth regulators also influence one another and are influenced by environmental factors. The action of plant growth regulators is a very active field of study.

Figure 2 Lack of sunlight has caused the plant on the right to grow in a tall and spindly manner.

plant growth regulator a chemical produced by plant cells that regulates growth and differentiation

tropism a directional change in growth or movement in response to a stimulus

phototropism a change in direction of a growing plant in response to light

Tropisms and Plant Growth Regulators

A **tropism** is a change in the direction of growth or movement of a plant in response to a stimulus. Tropisms are controlled by plant growth regulators. The existence of plant growth regulators was first hypothesized by Charles Darwin and his son Francis when they were investigating a tropism. They were attempting to explain why seedlings grown in a sunny window bend toward the light. This is called **phototropism**, which is a change in the direction of growth of a plant in response to light. The plant is detecting, and responding to, uneven lighting in its environment.

The Darwins carried out several experiments with a monocot grass species. These are summarized in **Figure 3**. In the first experiment they removed the shoot tip of some of the plants. When placed in a sunny window, plants with the tip bent toward the light, but those without the tip did not (**Figure 3(a)**). The Darwins concluded that the tip might produce a substance in response to the light. However, cutting off the tip might have damaged the plant so that it could not grow normally. Therefore, they carried out a second experiment. Instead of cutting off the shoot tips, they covered one with an opaque cap and one with a translucent cap. Light could pass through only the translucent cap. As demonstrated in **Figure 3(b)**, only the plants with translucent caps bent toward the light. The Darwins concluded that when a seedling is illuminated from one side, an unknown factor is transmitted from the seedling's tip to the tissue below, which causes it to bend toward the light.

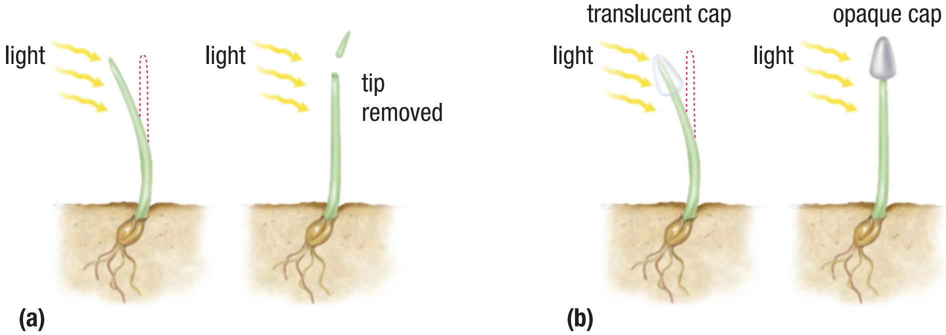

Figure 3 Darwin's phototropism experiments led him to hypothesize that plants produce substances that regulate their growth. (a) Plants with intact tips bend toward light, while plants with tips removed do not. (b) When the tip is covered with an opaque cap that blocks light, the seedling does not bend. When the cap is translucent and allows light to pass through to the tip, the seedling bends.

gravitropism a directional change in growth pattern in response to gravity

thigmotropism a directional change in growth pattern in response to touch

WEB LINK

To view animations of plant tropisms,

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There are several other types of tropism. **Gravitropism** is a change in the direction of growth in response to gravity. The tree in Figure 1 (page 613) shows gravitropism. When a seed germinates, gravitropism causes the emerging root to grow downward and the emerging shoot to grow upward. If a bulb is planted upside down, the roots and shoots will still grow in the correct direction. However, the plant may run out of stored energy before the shoot emerges from the ground. This is why packaged bulbs usually have a diagram to show the correct way to plant.

Some plants show **thigmotropism**, which is a change in the direction of growth in response to contact. Climbing vines, such as beans and peas, often show thigmotropism (**Figure 4(a)**). Plants carry out all of these tropisms (**Figure 4(b)**).

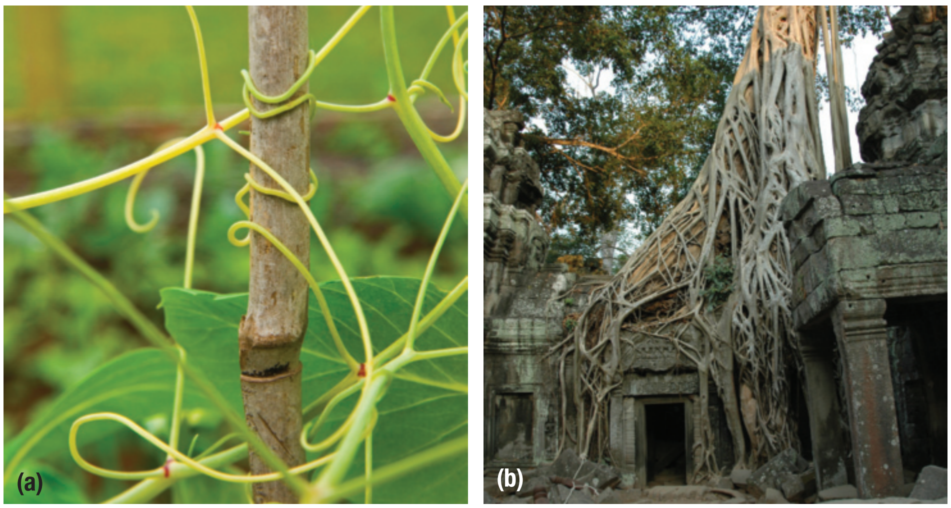

Figure 4 (a) The tendrils on this pea plant are modified leaves that show thigmotropism. (b) Thigmotropism and gravitropism help this banyan tree support itself.

Auxins

Auxins are a group of compounds that act in similar ways on plant growth and cell differentiation. The shoot apical meristem is the main site of auxin synthesis. The primary role of auxins is to promote cell elongation. The unknown substance that the Darwins thought the tip of a growing seedling produced is auxin. Scientists have since shown that during phototropism, the side of the plant closest to light contains less auxin than the side shaded from the light. As a result, the cells on the shaded side are stimulated to elongate. The relative difference in cell size causes the stem to bend (**Figure 5**). As a result, the plant maximizes the amount of light it receives.

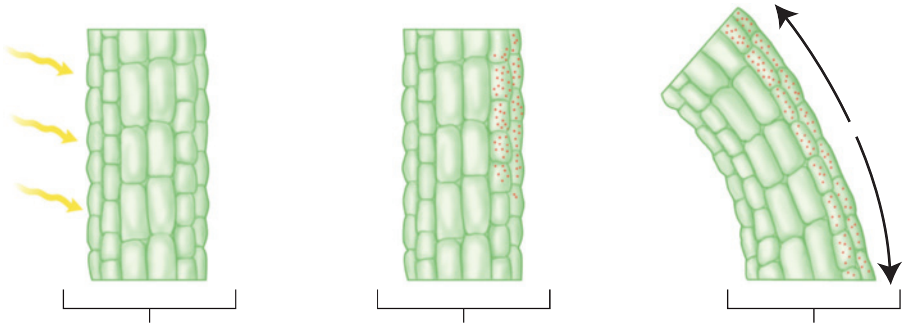

Figure 5 The effects of auxin on cells

When plants are commercially grown indoors, artificial lighting is usually placed directly overhead to avoid phototropism. This ensures that plants have thicker, straighter stems (**Figure 6**).

Figure 6 The plants in this growth room do not show phototropism because the lighting is directly overhead.

Some herbicides contain auxins that cause plants to undergo cell elongation at an unsustainably rapid rate. The rapid growth causes them to outstrip their carbohydrate supply, run out of energy, and die. Synthetic auxins may also be used by commercial fruit growers to induce cell elongation in fruits. By spraying an orchard with an auxin solution, fruit ripening can be artificially synchronized in all the plants. This reduces the cost of harvesting the fruit, because most of the fruit can be picked at one time. Growers therefore do not have to pay pickers to pick several times.

Auxins also inhibit cell division in some tissues. The best known example of this occurs in apical dominance. In **apical dominance**, cell division occurs in the apical bud but is inhibited in the lateral buds. Apical dominance is caused by the high level of auxin released by the apical meristem. Growers often stop apical dominance by cutting off the apical bud. This removes the main source of auxin and causes the lateral buds to develop. The resulting plant is shorter and has more branches than if the apical bud had not been removed. A grower can cause a plant to produce more flowers, fruit, or leaves by removing the apical bud. For example, basil plants can be made bushier by removing the apical bud at the end of each stem (**Figure 7**).

apical dominance the condition in which most shoot growth arises from the apical bud and not lateral buds

Figure 7 An apical bud on a basil plant (centre). Removing the apical bud results in more branching and more leaves.

Auxin also stimulates cell division in the vascular cambium and promotes the formation of new lateral meristems and new root apical meristems. Auxins are therefore included in rooting compounds, which are used to induce the formation of new root meristems from plant cuttings. Auxin also helps to regulate gravitropism.

Gibberellins

Figure 8 Gibberellin has been shown to stimulate the rapid stem elongation that happens when plants, such as these lettuces, bolt.

Gibberellins are a family of compounds that share a similar chemical structure and act in similar ways in plant cells. To date, more than 100 different gibberellins have been identified. Gibberellins play a role in many different growth and differentiation processes. High levels of gibberellins are produced by young tissues of shoots and by developing seeds, but leaves and young roots may also produce them.

The action of gibberellins is highly variable. Gibberellins promote cell division and cell elongation, depending on the tissue they are affecting. Environmental factors can also modify the effect of gibberellins on different plant tissues. However, gibberellins do appear to have a strong effect on the size of a plant. Many dwarf plant varieties are small because they produce very low levels of gibberellins.

Gibberellins also play a role in flowering and fruit production in many species. In fact, grape growers sometimes spray their crops with a gibberellin solution to induce fruit production. The gibberellin spray also causes the fruit stems to elongate, which gives more space for each individual grape to grow. As a result, individual grapes are larger. This makes grape bunches much larger and more appealing to buyers.

Studies have shown that gibberellins help make stored carbohydrate reserves available to the growing embryo. They also play a role in the response of plants to temperature changes. For example, when plants such as cabbage and lettuce experience a cold period, they bolt and go to seed. Bolting is rapid stem elongation that happens prior to flowering in some species (**Figure 8**). Seed producers may induce bolting by spraying plants with gibberellins.

Cytokinins

Cytokinins share a similar chemical structure, and they all promote cell division. They are found in tissues that are actively dividing, such as meristems, young leaves, and growing seeds. Cytokinins help to stimulate cell division in lateral buds when an apical bud has been removed. The effect of cytokinins on plant tissues depends on the presence of other plant growth regulators. The normal development of shoots and roots in a growing plant is regulated by the interaction of cytokinins and auxins.

Cytokinins also slow cell aging in certain plant organs by inhibiting protein breakdown and stimulating protein synthesis. Synthetic cytokinins are commonly sprayed on lettuce and mushrooms to keep them from spoiling. This effect may be related to inhibiting the effects of ethylene, another plant growth regulator.

Ethylene

Figure 9 Ethylene plays a role in senescence, including the leaf drop that occurs in the fall.

senescence developmental events in a plant tissue or organ from maturity to death

Ethylene, a gas, is a plant growth regulator that is produced by plants at various stages of development. Ethylene is sometimes called "the plant stress hormone" because it induces changes that protect a plant against environmental stress. For example, ethylene stimulates plants to lose their leaves in drought conditions. Recent studies suggest ethylene may have a role in the responses of plants to human-made environmental stresses. For example, an increase in ozone, an air pollutant, reduces crop yields. Recent studies show that an increase in atmospheric ozone increases ethylene production in plants. Ethylene also regulates the growth of roots and shoots around obstacles. For example, if a root touches a stone, the roots cells are stimulated to produce ethylene, which causes the root to grow sideways. When root cells no longer touch the stone, ethylene is no longer produced and the root grows downward again. Ethylene is also released at the site of a wound on a plant.

Ethylene also stimulates many developmental stages. These include fruit ripening, shoot and root growth and differentiation, flower opening, leaf and fruit drop (release from the stem), and flower and leaf senescence. **Senescence** refers to development processes that occur between maturity and death (**Figure 9**). As with the other growth regulators, the particular effect of ethylene depends on the species, the tissue or organ, and the levels of other plant growth regulators.

The role of ethylene in fruit ripening has great economic importance. Fruits release ethylene as they ripen, which induces further ripening and, eventually, spoilage. Fruit producers therefore try to control ethylene levels from the time a fruit is picked to when consumers buy it in the supermarket. To prevent ethylene production, producers ship fruit in well-ventilated trucks that contain ethylene-absorbing filters. Produce that is particularly sensitive to ethylene, such as broccoli, cabbage, and lettuce, is shipped separately from high ethylene producers, such as apples, bananas, and tomatoes. Ethylene may also be released into airtight shipping containers so that the produce all ripens at the same time. This helps the produce sell more readily. At home, you can ripen fruit by enclosing it in a plastic bag with a ripe banana. Ripe bananas produce high levels of ethylene.

Abscisic Acid

The primary role of abscisic acid (ABA) is to inhibit growth. ABA levels rise in response to changes in temperature and light, such as those occurring with the changing seasons. ABA maintains dormancy in leaf buds and seeds. Dormancy is a period of time when a plant or seed does not grow (**Figure 10**).

Dormant plants are less vulnerable to damage than actively growing plants. This is one reason why deciduous trees are dormant over winter and why grasses become dormant and turn brown during hot, dry periods in summer. ABA is sometimes applied to plants before they are shipped from nurseries to garden centres for the same reason. Once the plants have reached their destination, the ABA-induced dormancy can be reversed by spraying the plants with a gibberellin spray.

Another important role of ABA is to control the closing of stomata when the environment is dry. When they have insufficient water, plants wilt. Wilting induces mesophyll cells in the leaf to produce ABA. This ABA diffuses to the guard cells of the stomata and induces them to close, allowing the leaves to conserve their internal water.

Figure 10 ABA keeps buds dormant until the right light and temperature conditions exist to support their growth.

Using Plant Growth Regulators in Plant Tissue Culture

Plant tissue culture is a technology that can be used to produce many clones of plants with desirable traits. **Figure 11** shows a common procedure in plant tissue culture. Each bumpy mass of shoots you see on the Petri dish was produced from a tiny stem segment taken from an intact plant. How? First, the scientist placed the stem segment on a tissue culture medium containing plant growth regulators that induced the cells to divide. Once its cells started to divide, the stem segment was moved to a culture medium containing plant growth regulators that induced shoot differentiation.

CAREER **LINK**

Lab Technician
Lab technicians may work in institutions or companies that are involved in plant tissue culture. For more information about a career as a lab technician,

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Figure 11 These newly formed shoots are clones, produced from the stem of a single plant. They will next be transferred onto a culture medium that will induce them to produce roots.

Through experiments using plant tissue culture, scientists have been able to show that it is usually the ratio of different plant growth regulators that determines the type of growth or differentiation that is induced. The ratios between cytokinins and auxins have been well described. A scientist can control the type of tissue produced by changing the ratio of these two plant growth regulators in the culture medium. If cytokinins are entirely absent in the medium, auxin causes the cells to just enlarge and they do not divide. If auxins are absent, cytokinins have no effect on cells. If cytokinin levels are high relative to auxins, the cells differentiate into shoots. But when auxin levels are high relative to cytokinins, the cells differentiate into roots.

Plant tissue culture was initially used exclusively for research on plant growth regulators and other compounds that might affect plants. Today, it has commercial applications. It is used to produce large quantities of identical individuals for breeding programs. The technique is especially useful for propagating tree species. It can take many years to produce tree species by natural means, and tissue culture can quickly produce many copies of an individual with desirable traits. Unfortunately, individuals produced in this way have no genetic diversity.

13.6 Summary

- Plant growth regulators are substances produced by the plant that regulate its growth and development.
- Changes in environmental factors can change the levels of plant growth regulator.
- The effect of any plant growth regulator depends on the tissue, the plant species, and the levels of other plant growth regulators.
- Auxins and gibberellins induce cell elongation in many tissues.
- Cytokinins induce cell division in many tissues.
- Ethylene regulates fruit ripening and stress responses in many plants.
- Abscisic acid inhibits growth and promotes dormancy in many species. It also induces the closing of stomata during water stress.

13.6 Questions

1. Name the five plant growth regulators that are found in most plants. K/U
2. Which plant growth regulators primarily promote cell elongation? Which primarily promote cell division? K/U
3. Describe how the Darwins were able to show that phototropisms in grasses are influenced by light reaching the growing tips of plants. K/U A
4. A growth response toward a stimulus is called a positive tropism, while a growth response away from a stimulus is called a negative tropism. Use these terms to describe the phototropisms and gravitropisms of roots and shoots. K/U C
5. How can an understanding of apical dominance be used to produce plants that have more lateral branches? In what way is this technique influencing the production of plant regulators within the plant? K/U A
6. Suggest a possible technique that might help achieve the following results: T/I A
   (a) produce grapes that are larger than normal
   (b) help plants survive while being shipped over long distances to garden centres
   (c) ensure that fruits do not become too ripe before they are ready to be sold in supermarkets
   (d) stimulate cells in tissue culture to produce roots
7. Nastic movements are an interesting type of plant response. They include the opening and closing of some flowers during the day and the sudden closing of a venus fly trap. Use the Internet and other sources to research and view video clips of nastic movements. T/I A
   (a) How do nastic movements differ from tropisms?
   (b) How are plants able to move tissues rapidly, as in the case of the venus fly trap?
   (c) How do the leaves of the Mimosa plant respond to touch?

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