CHAPTER 22

Plants with Seeds



This bee is busy gathering nectar from flowers. Pollen produced by the flowers sticks to the bee's body. An oak tree produces more than enough acorns to satisfy hungry squirrels and more than enough to produce new oaks.

Try to imagine what life would be like without plants. It's a rather difficult image to conjure up, especially because without plants there would be no animals. Almost every animal on the face of the Earth ultimately depends on food produced by plants. And just as importantly, plants shape environments in which animals live.

Humans and other land animals are able to benefit from plants only because members of one certain plant group have evolved in ways that allow them to live in a variety of different places. Most mosses and ferns cannot survive in many habitats because they need an almost constant supply of water. But seed plants—which include nearly all the plants you encounter—have, as a result of many evolutionary changes, been freed from dependence on water. It is this evolutionary story that you will uncover in this chapter.

CHAPTER OUTLINE

22–1 Seed Plants—The Spermopsida
- Seed Plants—Designed for Life on Land
- Roots, Stems, and Leaves
- Vascular Tissue
- Reproduction Free from Water

22–2 Evolution of Seed Plants
- Seed Ferns
- Gymnosperms
- Conifers: Cone Bearers
- Angiosperms: Flowering Plants

22–3 Coevolution of Flowering Plants and Animals
- Flower Pollination
- Seed Dispersal

22–1 Seed Plants—The Spermopsida

Section Objectives

- Describe several adaptations of seed plants to life on land.
- Identify the functions of roots, stems, and leaves.
- Explain why reproduction in seed plants is not dependent upon water.

Compared to life in water, life on land offers several benefits to plants. Life on land provides abundant sunlight for photosynthesis. On land there is continuous free movement of gaseous carbon dioxide and oxygen, which plants use during photosynthesis and respiration.

But life on land also presents significant problems to plants. Water and nutrients are available to most land plants only from the soil. On land, dry air draws water from exposed plant tissues by the process of evaporation. On land, photosynthetic tissues must be held upright to capture sunlight. And unlike the reproductive cycles of mosses and ferns, the reproductive cycles of most land plants must work without standing water.

Seed Plants—Designed for Life on Land

Seed plants, members of the subphylum Spermopsida, exhibit numerous adaptations that allow them to survive the difficulties of life on land. Note that seed plants did not evolve

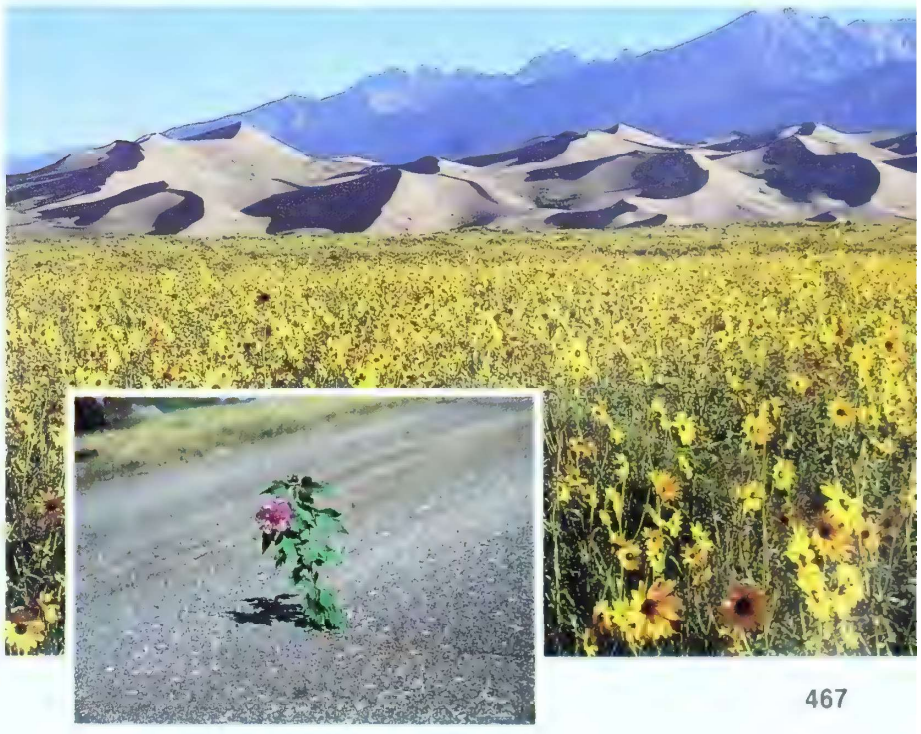
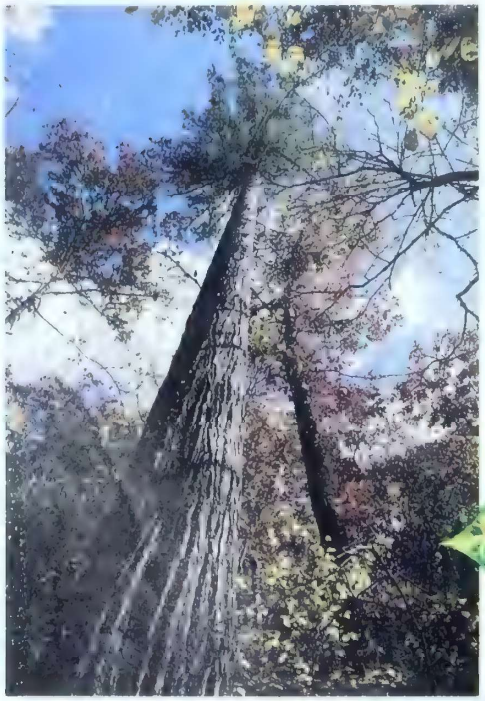


Figure 22–1 *Fields of sunflowers follow the daily movement of the sun. Here thousands of plants grow in conditions that are quite favorable. But plants often grow in less hospitable places, such as a tiny crack in the surface of a road.*

Figure 22–2 *Roots, such as these of a corn plant, anchor the plant in the soil (top). The stem of the white pine is strong enough to support the plant for many meters above the ground (bottom, left). The leaves of most plants are green, the color of chlorophyll. However, leaves such as those of the brilliantly colored croton often show other colors besides green (bottom, right).*





these adaptations because they "wanted" to or because the processes of evolution somehow "knew" that such adaptations would be useful on dry land. Rather, in every generation of plants, the types of genetic variations we discussed in earlier chapters produced individuals with different characteristics. Over time, those individuals with characteristics best suited to their environments survived and produced offspring.

In this way, over hundreds of millions of years, the ancestors of seed plants evolved a variety of new adaptations that enabled them to survive in many places in which mosses and ferns could not. These ancient plants evolved well-developed vascular tissues that conduct water and nutrients between roots and leaves. They evolved roots, stems, leaves, and structures that enable them to live everywhere—from frigid mountains to scorching deserts. And, seed plants, as their name implies, evolved seeds—the key adaptation in a new form of sexual reproduction that does not require standing water. Let us briefly examine these adaptations one at a time.

Roots, Stems, and Leaves

Just like the cells in your body, the cells in a plant are organized into different tissues and organs. The three main organs in a plant are roots, stems, and leaves. Each organ shows adaptations that make the plant better able to survive.

ROOTS Roots perform several important functions. They absorb water and dissolved nutrients from moist soil. They anchor plants in the ground. Roots also hold plants upright and prevent them from being knocked over by wind and rain. Roots are able to do all these jobs because as they grow, they develop complex branching networks that penetrate the soil and grow between soil particles.

STEMS Stems hold a plant's leaves up to the sun. Although plenty of sunlight reaches the Earth, plants compete



with one another for this solar energy. Many plants have tall stems and branches that reach above other plants around them. To support such tall plants, stems must be very sturdy.

LEAVES Leaves are the organs in which plants capture the sun's energy—a process vital to photosynthesis. Leaves evolved because plants that had broad, flat surfaces over which to spread their chlorophyll were able to capture more solar energy than plants that did not have such surfaces. So over time, in most habitats, plants with leaves had higher fitness—and produced more offspring—than plants without leaves. But those broad, flat leaves also exposed a great deal of tissue to the dryness of the air. These tissues must be protected against water loss to dry air. That's why most leaves are covered with a waxy coating called the cuticle. Because water cannot pass through the cuticle, this coating slows down the rate of evaporation of water from leaf tissues. Adjustable openings in the cuticle help conserve water while allowing oxygen and carbon dioxide to enter and leave the leaf as needed.

Vascular Tissue

As plants evolved longer and longer stems, the distance between their leaves and roots increased. The leaves of a tall tree might be 100 meters above the ground. Thus tall plants face an important challenge: Water must be lifted from roots to leaves, and compounds produced in leaves must be sent down to roots. Over time, the evolutionary forces of variation, chance, and natural selection produced a well-developed vascular system. This remarkable two-way plumbing system consists of two kinds of specialized tissue: xylem and phloem.

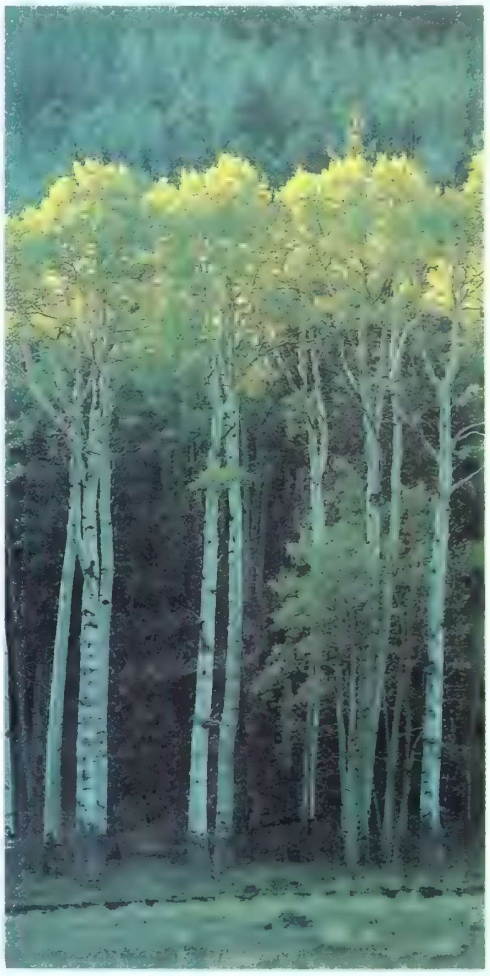
XYLEM Xylem is the vascular tissue primarily responsible for carrying water and dissolved nutrients from the roots to stems and leaves. Because xylem cells often have thick cell walls, they also provide strength to the woody parts of large plants such as trees. Oddly enough, most xylem cells grow to maturity and die before they function as water carriers.

PHLOEM Phloem tissue carries the products of photosynthesis and certain other substances from one part of the plant to another. Whereas xylem cells conduct water in only one direction (upward), phloem cells can carry their contents either upward or downward. Unlike xylem cells, functioning phloem cells are alive and filled with cytoplasm.

Reproduction Free from Water

Like other plants, seed plants have alternation of generations. However, the life cycles of seed plants are well-adapted to the rigors of life on land. All of the seed plants you see

Figure 22–3 *Growing tall can be an advantage to a plant's survival. Tall plants receive more of the sun's light and are less likely to be shaded by other plants. Vascular tissues transport water from the roots to leaves at the tallest part of a plant.*



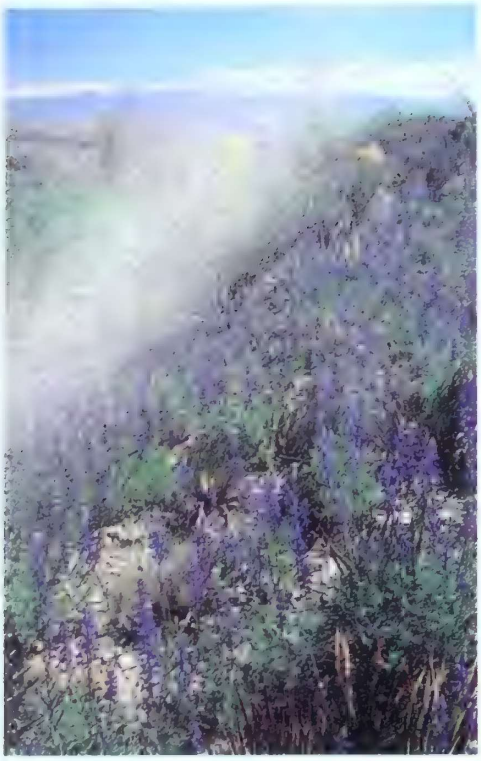
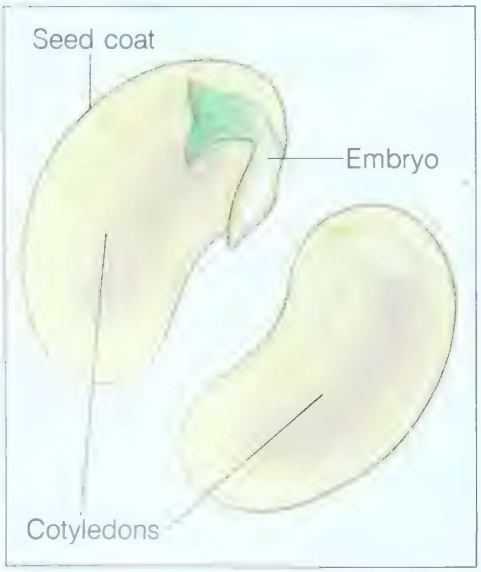


Figure 22–4 *Texas bluebonnets are a wildflower that grows in huge numbers. Flowers are a plant's reproductive structures.*

Figure 22–5 *Seeds are a promise and a plant's insurance. A seed contains the promise of a plant to come and the insurance that a species will have a chance to survive.*



around you are members of the sporophyte generation. By comparison, the gametophytes of seed plants are tiny, consisting of only a few cells. This size difference can be seen as the final result of an evolutionary trend in plants in which the gametophyte becomes smaller as the sporophyte becomes larger.

FLOWERS AND CONES The tiny gametophytes of seed plants grow and mature within the parts of the sporophyte we call flowers and cones. Flowers and cones are special reproductive structures of seed plants, which we shall discuss later. Because they develop within the sporophyte plant, neither the gametophytes nor the gametes need standing water to function. Thus the special reproductive structures of seed plants (flowers and cones) can be considered important adaptations that have contributed to the success of these plants.

POLLINATION The entire male gametophyte of seed plants is contained in a tiny structure called a **pollen grain**. Sperm produced by this gametophyte do not swim through water to fertilize the eggs. Instead, the entire pollen grain is carried to the female gametophyte by wind, insects, birds, small animals, and sometimes even by bats. The carrying of pollen to the female gametophyte is called **pollination**. Pollination is an important process that we shall discuss shortly.

SEEDS Seeds are structures that protect the zygotes of seed plants. After fertilization, the zygote grows into a tiny plant called an **embryo**. The embryo, still within the seed, stops growing while it is still quite small. When the embryo begins to grow again later, it uses a supply of stored food inside the seed. A **seed coat** surrounds the embryo and protects it and the food supply from drying out. Inside the seed coat, the embryo can remain dormant for weeks, months, or even years. Seeds can survive long periods of bitter cold, extreme heat, or drought—beginning to grow only when conditions are once again right. Thus the formation of seeds allows seed plants to survive and increase their number in habitats where mosses and ferns cannot.

22–1 SECTION REVIEW

1. What are three adaptations of seed plants that enable them to live on land?
2. What are the functions of roots, stems, and leaves?
3. How are xylem and phloem tissues similar? How are they different?
4. What is a seed? Why are seeds important to plant life on land?

22–2 Evolution of Seed Plants

Section Objectives

- Describe the evolution of seed plants.
- List several characteristics of gymnosperms and angiosperms.
- Compare monocots and dicots.

The history of plant evolution is marked by several great adaptive radiations. **Each time a group of plants evolved a useful new adaptation (such as vascular tissue or seeds), that group of plants gave rise to many new species.** Because of the new adaptation, some new species were able to survive in previously empty niches. For other new species, the new adaptation made them better suited to their environments than existing species that did not possess the new adaptation. Over time, the better adapted species survived and the older species became extinct.

It is important to remember that Earth's environments did not remain constant through time. Over a period of millions of years, landmasses moved and mountain ranges rose. In some cases, plant species produced by an adaptive radiation continued to evolve in ways that enabled them to survive as their environment changed. Such species survived for long periods. In other cases, plant species could not survive changing environments. These species became extinct.

Mosses and ferns, for example, underwent major adaptive radiations during the Devonian and Carboniferous periods, 300 to 400 million years ago. During these periods, land environments were much wetter than they are today. Tree ferns, tree lycopods, and other spore-bearers grew into lush forests that covered much of the Earth.

But over a period of millions of years, continents became much drier, making it harder for spore-bearing plants to survive and reproduce. For that reason, many moss and fern species became extinct. They were replaced by seed plants whose adaptations equipped them to deal with drier conditions. To help you understand how seed plants became successful, we shall now trace the evolution of these fascinating organisms.

Figure 22–6 *Seed ferns are part of the fossil record. They represent a link between ferns that do not form seeds and seed plants that do. This ancient plant had leaves that resemble the leaves of modern ferns.*



Seed Ferns

The first seed-bearing plants, which appeared during the Devonian Period, resembled ferns. But these plants were different from ordinary ferns in one very important respect: They reproduced by using seeds instead of spores. Fossils of these so-called seed ferns document several evolutionary stages in the development of seed plants. Although seed ferns were quite successful for a time, they were rapidly replaced by other plant species. Today, no seed ferns survive.

Gymnosperms

The most ancient surviving seed plants belong to three classes: the Cycadae, Ginkgoae, and Coniferae. In plants of these classes, a number of leaves have evolved into specialized male and female reproductive structures called **scales**. Scales





Figure 22–7 *Confusingly named the sago palm, this cycad is not a palm at all (left). Cycads grow primarily in warm and temperate areas. Cycads produce reproductive structures that look like giant pine cones (right).*

Figure 22–8 *The Ginkgo is often planted on city streets because it can tolerate the air pollution produced by city traffic.*



are grouped into larger structures called male and female cones. Male cones produce male gametophytes called pollen. Female cones produce female gametophytes called eggs. Later, the female cones hold seeds that develop on their scales. Each seed is protected by a seed coat, but the seed is not covered by the cone. Because their seeds sit "naked" on the scales, Cycads, Ginkgoes, and Conifers are called naked seed plants, or **gymnosperms** (*gymno-* means naked; *-sperm* means seed).

CYCADS Cycads are beautiful palmlike plants that first appear in the fossil record during the Triassic Period, 225 million years ago. Huge forests of cycads thrived when dinosaurs roamed the Earth. Many biologists think that some species of dinosaurs ate the young leaves and seeds of cycads. Today, only nine genera of cycads, including the confusingly named sago palm, remain. Cycads can be found growing naturally in tropical and subtropical places such as Mexico, the West Indies, Florida, and parts of Asia, Africa, and Australia.

GINKGOES Ginkgoes were common when dinosaurs were alive, but today only a single species, *Ginkgo biloba*, remains. The living ginkgo species looks almost exactly like its fossil ancestors, so it is truly a living fossil. In fact, *Ginkgo biloba* may be the oldest seed plant species alive today. This single species may have survived only because the Chinese have grown it in their gardens for thousands of years.

Conifers: Cone Bearers

Conifers, commonly called evergreens, are the most abundant gymnosperms today. They are also the most familiar and important. Pines, spruce, fir, cedars, sequoias, redwoods, and yews are all conifers. Some conifers, such as the dawn redwood, date back 400 million years to the Devonian Period—well before the time of the cycads. But although other classes of gymnosperms are largely extinct, conifers still cover vast

areas of North America, China, Europe, and Australia. Conifers grow on mountains, in sandy soil, and in cool moist areas along the northeast and northwest coasts of North America. Some conifers live more than 4000 years and can grow more than 100 meters tall.

ADAPTATIONS The leaves of conifers are long and thin, and are often called needles. Although the name evergreen is commonly used for these plants, it is not really accurate because needles do not remain on conifers forever. A few species of conifers, like larches and bald cypresses, lose their needles every fall. The needles of other conifer species remain on the plant for between 2 and 14 years. These conifers seem as if they are "evergreen" because older needles drop off gradually all year long and the trees are never completely bare.

REPRODUCTION Like other gymnosperms, most conifers produce two kinds of cones. The scales that form these cones carry structures called sporangia that produce male and female gametophytes. Both male and female gametophytes are very small. Male cones, called **pollen cones**, produce male gametophytes in the form of pollen grains. Female cones, called seed cones, house the female gametophytes that produce ovules. Some species of conifers produce male and female cones on the same plant, whereas other species have separate male and female plants.

Each spring, pollen cones release millions of dustlike pollen grains that are carried by the wind. Many of these pollen grains fall to the ground or land in water and are wasted. But some pollen grains drift onto seed cones (female cones), where they may be caught by a sticky secretion. When a pollen grain lands near a female gametophyte, it produces sperm cells by mitosis. These sperm cells burst out of the pollen grain and fertilize ovules. After fertilization, zygotes grow into seeds on the surfaces of the scales that make up the seed cones. It may take months or even years for seeds on the female cones to mature. In time, and if they land on good soil, the mature seeds may develop into new conifers.

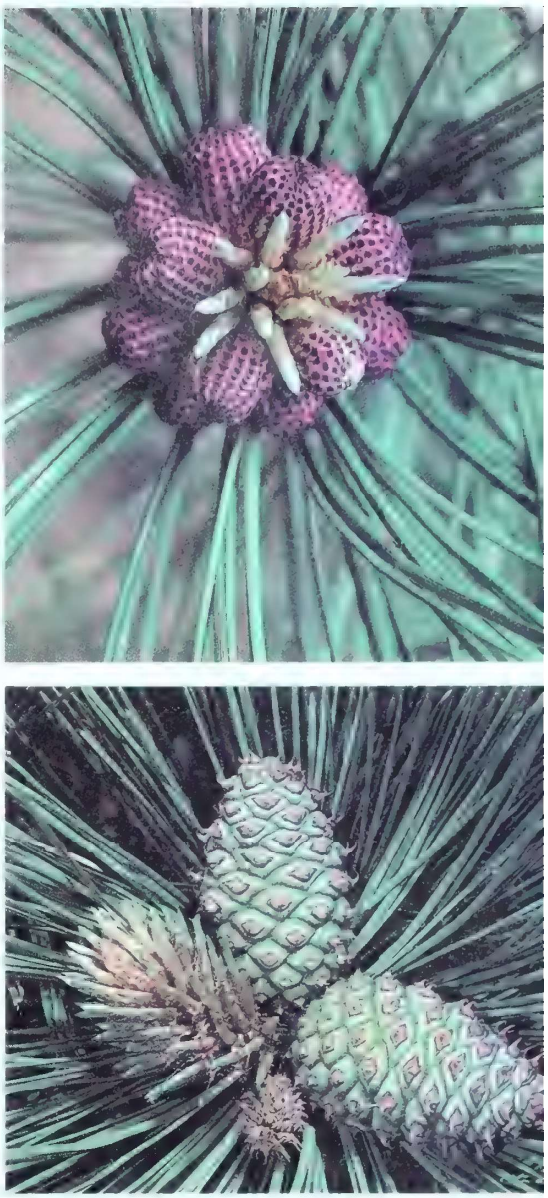


Figure 22–9 *Pine cones may be either male or female. Male cones (top) produce windborne pollen that is carried to female cones (bottom). Female cones nurture and protect the developing seeds, which often take two years to mature.*

Angiosperms: Flowering Plants

Angiosperms are the flowering plants. All angiosperms reproduce sexually through their **flowers** in a process that involves pollination. Unlike the seeds of gymnosperms, the seeds of angiosperms are not carried naked on the flower parts. Instead, angiosperm seeds are contained within a protective wall that develops into a structure called a **fruit**. The scientific term fruit refers not only to the plant structures normally called fruits but also to many structures often called vegetables. Thus, by definition, apples, oranges, beans, pea pods, pumpkins, tomatoes, and eggplants are all fruits.



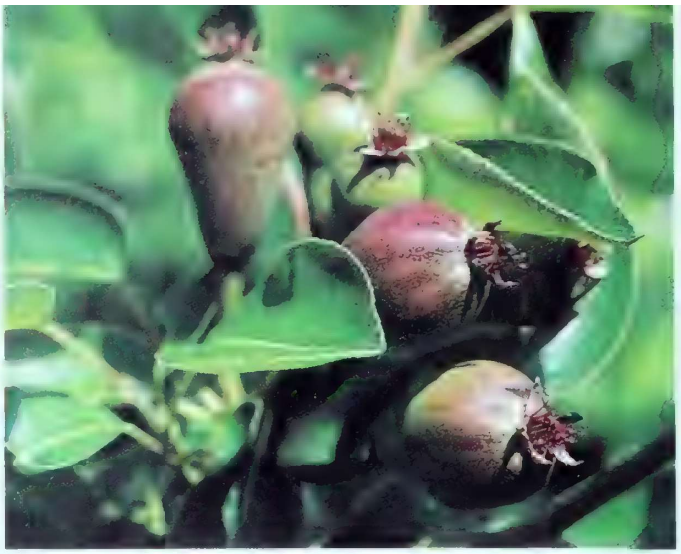


Figure 22–10 *These pear flowers are a form of floral advertising that attracts bees and other insects. The insects pollinate the flowers. Six weeks after pollination has occurred, the developing pears are still quite small. In time they will ripen.*

Today, angiosperms are the most widespread of all land plants. More than a quarter of a million species of angiosperms live everywhere from frigid mountains to blazing deserts, from humid rain forests to temperate backyards near your home. Some angiosperms even live under water. Different species of angiosperms have evolved specialized tissues that allow them to survive extreme heat and cold, as well as long periods of drought.

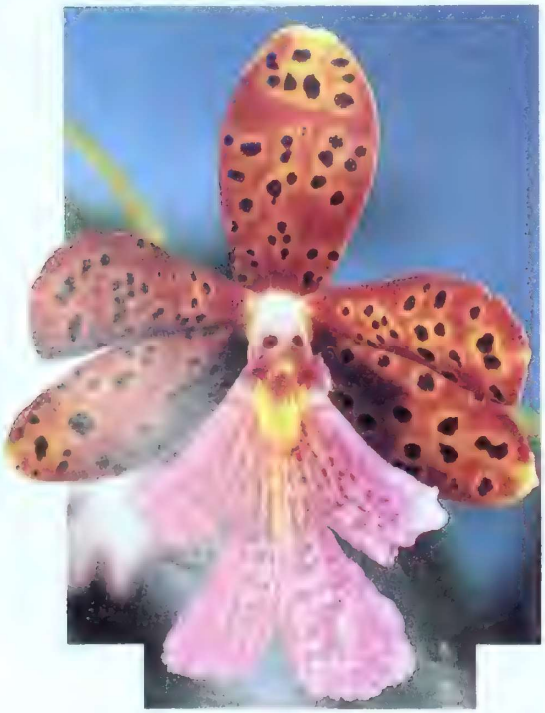
Angiosperms can be separated into two subclasses: the Monocotyledonae (mahn-oh-kaht-'l-EED-'n-ee), called monocots for short, and the Dicotyledonae (digh-kaht-'l-EED-'n-ee), called dicots for short. The **monocots** include corn, wheat, lilies, daffodils, orchids, and palms. The **dicots** include plants such as roses, clover, tomatoes, oaks, and daisies.

There are several differences between monocots and dicots. The simplest difference has to do with the number of leaves the embryo plant has when it first begins to grow, or germinate. The leaves of the embryo are called **cotyledons**, or seed leaves. Monocotyledons have one seed leaf (*mono-* means one). Dicotyledons start off with two seed leaves (*di-* means two). In some species, cotyledons are filled with food for the germinating plant. In other species, the cotyledons are the first leaves to carry on photosynthesis for the germinating plant.

Figure 22–12 shows several characteristics of monocots and dicots. These differences are summarized below:

1. Veins in monocot leaves usually lie parallel to one another. Veins in dicot leaves form a branching network.
2. In monocot flowers, petals and other flower parts are usually found in threes or multiples of three (3, 6, 9, and so on). In dicot flowers, petals and other flower parts occur in fours or fives or in multiples of four (4, 8, 12) or five (5, 10, 15).
3. In monocot stems, xylem and phloem tissues are gathered into **vascular bundles** that are scattered throughout the stem. In dicot stems, these vascular bundles are arranged in a ring near the outside of the stem.

Figure 22–11 *Flowers can vary in appearance. This orchid flower is colorful and has petals and sepals of different shapes.*



	Monocots	Dicots
Leaves	Veins in leaves of most monocots are parallel to each other.	Veins in leaves form a branching network.
Flower	Flower parts in threes or multiples of three.	Flower parts in fours or fives or multiples of four or five.
Vascular bundles in stem	Vascular bundles are scattered in a cross section of a stem.	Vascular bundles are arranged in a ring in a cross section of a stem.
Vascular bundles in root	Bundles of xylem and phloem alternate with one another in a circle.	A single mass of xylem forms an "X" in the center of the root; phloem bundles are located between the arms of the "X."
Stem thickness	Stems of most monocots do not grow thicker from year to year.	Stems can grow thicker from year to year.

Figure 22–12 *Flowering plants are placed into two main subclasses, Monocotyledonae and Dicotyledonae. This chart identifies the differences between these two classes. Which class contains plants whose leaves have veins that are parallel to one another?*

4. In monocot roots, bundles of xylem and phloem alternate with each other in a circular arrangement, like the spokes of a bicycle wheel. In dicot roots, a single mass of xylem tissue forms an X in the center of the root, and bundles of phloem tissue are positioned between the arms of the "X."
5. Most monocots have stems and roots that do not grow thicker from year to year. For this reason there are very few treelike monocots. Palms are one of the few treelike monocots. Some dicot stems and roots can grow thicker from year to year. Most of the flowering trees you see are dicots.

22–2 SECTION REVIEW

1. What is a seed fern? Why is it important in the evolution of seed plants?
2. Compare gymnosperms and angiosperms.
3. Which generation is more obvious in seed plants? How do the relative sizes of these generations follow a trend in the evolution of plant reproduction?
4. Suppose you found a plant whose leaves have parallel veins and whose flowers have six petals. Is this plant a monocot or a dicot? What is your reasoning?



Figure 22–13 *This tiny bean seed has pushed its stem above the soil surface and into the light. Just below the leaves at the top of the plant, the two bean-shaped cotyledons remain attached to the stem. Later, when the plant is large enough to make its own food, the cotyledons will shrivel and fall off.*

Section Objectives

- Describe the process of pollination in seed plants.
- Explain plant-animal coevolution.
- Discuss the importance of seed dispersal to the success of the seed plants.

22–3 Coevolution of Flowering Plants and Animals

Watching bees travel from flower to flower is such a common experience that most of us probably do not think about it. We take for granted the fact that flowers are brightly colored and beautifully perfumed. Rarely do we wonder why fruits are tasty and nutritious as well as colorful. But how and why did insects begin exhibiting flower-visiting behavior? When did animals begin to eat fruits and seeds? And why have plant flowers and fruits evolved into their present forms?

The process by which two organisms evolve structures and behaviors in response to changes in each other over time is called **coevolution**. Some of the most fascinating examples of coevolution involve relationships between angiosperm flowers and fruits and a wide variety of animal species.

To understand plant-animal coevolution, we must look once again at the evolutionary history of plants. The first flowering plants probably evolved during the early Cretaceous Period, about 125 million years ago. At that time, gymnosperms and other plants formed huge forests. Dinosaurs were the dominant land animals. During the Cretaceous Period, the first birds and mammals began to appear in the fossil record. Flying insects, particularly beetles of several types, became common. Thus the first flowering plants evolved at about the same time as the earliest mammals, a short time after the earliest birds, and a good while after the earliest insects.

Then, toward the end of the Cretaceous Period, the Earth's climate changed dramatically. Dinosaurs and many gymno-





Figure 22–14 Many different animals pollinate plants. Bees, such as this honeybee covered with pollen, are perhaps the most common (right). Bees are responsible for the pollination of many of the plant varieties that produce the fruits we eat. Bananas, like this one growing in Southeast Asia, are often pollinated by bats, not by bees (left).

sperms became extinct. This mass extinction opened up many niches for other organisms. New adaptive radiations of both animals and plants occurred. New species of birds and mammals evolved and filled niches vacated by the dinosaurs. New species of angiosperms replaced disappearing gymnosperms. And many new species of insects—including moths, bees, and butterflies—evolved.

The coincidence of angiosperm evolution with the evolution of modern insects, birds, and mammals is very important. Flowers and fruits are specialized reproductive structures that could evolve only in the presence of insects, birds, and mammals. Let us now see how and why this is so.

Flower Pollination

Pollination is essential to the reproduction of flowering plants. Over millions of years, a variety of ways to ensure that pollination will occur has evolved. For example, some plants are pollinated by the wind. Wind-pollinated plants include willow trees, ragweed, and grasses such as corn and wheat. The tiny pollen grains of these plants fall off their flowers without difficulty, making it easy for them to be carried by the wind to other flowers. Wind-pollinated plants usually have small, plain simple flowers with little or no fragrance.

But most angiosperms are not pollinated by the wind. Most flowering plants are pollinated by insects, birds, or mammals that carry pollen from one flower to another. In return, the plants provide the pollinators with food. The food may take the form of pollen or a liquid called nectar, which may contain up to 25 percent glucose, or a combination of pollen and nectar.

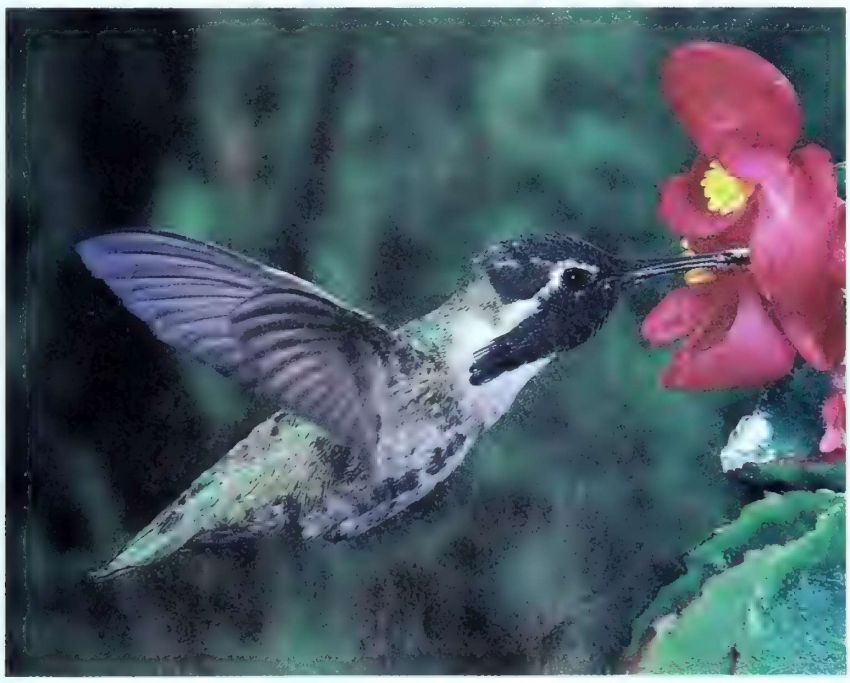


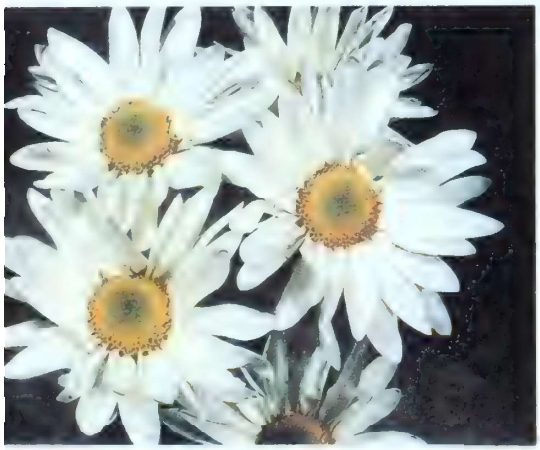
Figure 22–15 *Hummingbirds are able to flap their wings so fast that they hover in place. This hummingbird is drinking nectar from a flower. Because hummingbirds are able to see red and orange quite well, they are attracted to these flower colors.*

It is easy to imagine how pollinators such as bees first learned to visit certain flowers. When a bee finds food on a particular flower, it remembers clearly the color, shape, and odor of that flower. So if a bee finds edible pollen on a flower of a particular type, it will search for more flowers of that same type. While feeding on different flowers, a bee may accidentally pick up extra pollen that it then carries to the next flower it visits. Because the bees remember the color and odor of flowers so well, it is probable that pollen picked up from one flower will be deposited on another flower of the same species.

This kind of interaction between animals and plants increases the evolutionary fitness of both organisms. Insects benefit by learning to identify dependable sources of food. Plants benefit because this kind of **vector pollination**, or pollination by the actions of animals, is a very efficient way of getting the male gametophyte to the female gametophyte. Vector pollination is much more efficient than wind pollination, which wastes enormous amounts of pollen.

Of course, flowers that depend upon specific animals to pollinate them could only have evolved after those animals evolved. When angiosperms first appeared, this sort of relationship began accidentally. But over time the coevolutionary relationship strengthened because it proved beneficial to the survival of both plants and animals. Coevolutionary relationships can be very specific. The following examples of flower-pollinator pairs illustrate this fact.

Figure 22–16 *These flowers appear quite different to a human's eyes than they do to a bee's eyes. Under ultraviolet light, the white flowers glow with a strange purple hue, a color that is easily seen by foraging bees.*





One common pollinator is the honeybee. To attract bees to their flowers, many plants have brightly colored flower petals that bees can see well. Because bees can see ultraviolet, blue, and yellow light the best, these are the colors of most bee-pollinated flowers. We cannot see ultraviolet light under ordinary circumstances. But special film can make this color visible to our eyes. In Figure 22–16 you can see a picture of a flower taken in ultraviolet light. The petals of some flowers even have markings that point to the center of the flower. These markings are like a secret sign for bees alone to see! The markings direct the bee to the center of the flower—the source of nectar. On its way to the food, the bee might pollinate the flower, thus ensuring the survival of the plant species. Flowers that are pollinated by bees usually have some kind of landing platform because bees gather nectar only when they are standing, not when they are flying.

Flowers that have coevolved with animals other than bees show different methods of attracting pollinators. For example, some flowers are pollinated by night-flying moths that cannot see color but have an excellent sense of smell. The petals of these flowers are often plain and white, but the flowers themselves are very fragrant—especially at night. (We use many of these floral fragrances—jasmine, for example—in perfumes.) Moth-pollinated flowers usually do not have landing platforms because unlike bees, moths feed while hovering in midair. The

nectar of moth-pollinated flowers is usually contained deep within the flower, where only the long tongue of a moth can reach it.

Several species of flowers are pollinated by flies that lay their eggs in the bodies of dead and decaying animals. You certainly would not want to grow these flowers in your house because they smell like rotting meat! The smell produced by the flowers attracts the flies that are looking for a place to lay their eggs. The flowers of these plants even heat up when they are ready to be pollinated, thus intensifying the smell they produce to lure additional flies that may act as vector pollinators.

Some flowers are pollinated by birds. Birds have a very poor sense of smell but a good sense of sight. Birds can easily see the colors orange and red. Not surprisingly, bird-pollinated flowers, such as the beautiful bird-of-paradise flower, are a reddish-orange color. These flowers usually have no fragrance.

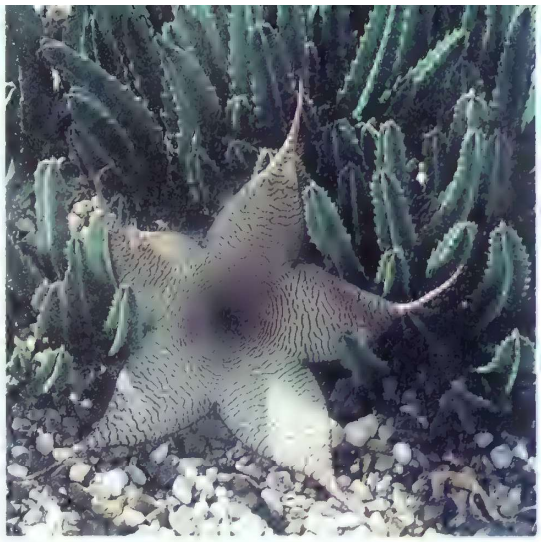


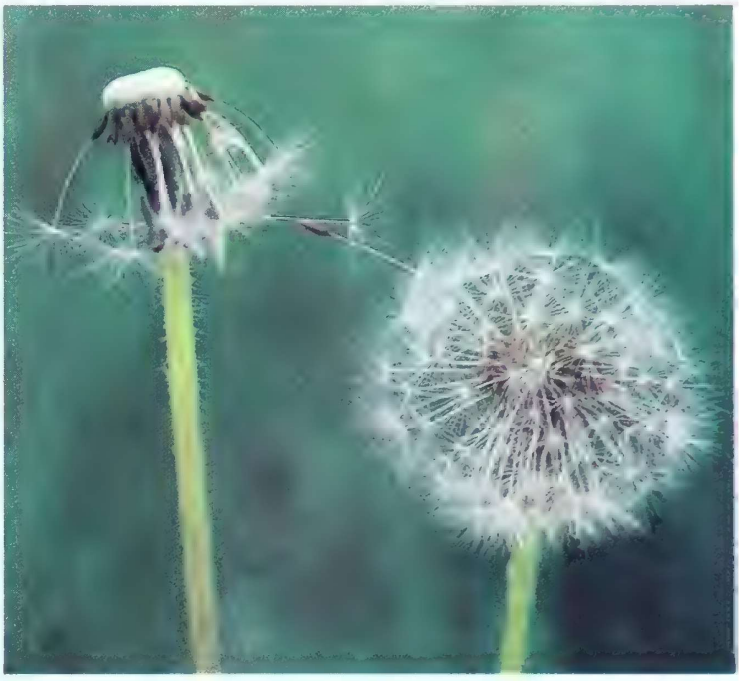
Figure 22–17 *The stapelia flower, also called the carrion flower, smells like a piece of rotting meat. Although not attractive to us, the smell proves alluring to a fly looking for a place to lay her eggs.*

Seed Dispersal

Just as flowers have different methods that ensure pollination, angiosperm fruits have adaptations that help scatter seeds away from the parent plant. The process of distributing seeds away from parent plants is **seed dispersal**. Seed dispersal is very important to plants. Why? If the seeds of a plant are not dispersed but instead fall to the ground beneath the parent plant, the seedlings will compete with one another and with the parent plant for sunlight, water, and nutrients. This competition will reduce the chances of survival for the growing seeds. Seed dispersal also enables plants to colonize new environments. Although adult plants cannot move around, their seeds can be carried to new environments.

Figure 22–18 *The seeds of the milkweed (left) and the dandelion (right) are carried by the wind.*



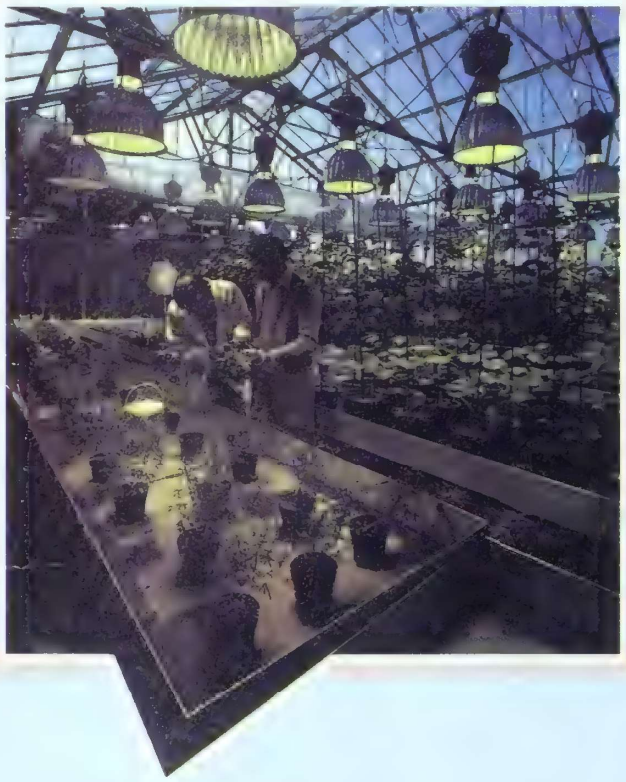


Designer Genes Create Better Plants

At one agricultural laboratory, a single tomato plant in a cage full of hungry caterpillars remains untouched while its neighbor is stripped bare of leaves. The cells of the protected tomato are able to manufacture an insecticide because of genes transplanted from a bacterium. At another laboratory, a newly developed potato manufactures a chemical that repels both potato beetles and leaf hoppers, two notorious insect pests. The new potato plant produces an insect repellant previously made only by a few varieties of wild potato from South America.

These are just two of the new and improved plant varieties being produced by the application of biotechnology to agriculture. Using a variety of techniques (including techniques of genetic engineering you read about in Chapter 12) researchers are now designing and producing new plants that exhibit traits breeders could once only dream about.

With genes transplanted from other organisms, such as bacteria, plants may be able to manufacture their own insecticides. These insecticides do not harm the environment because they remain within the plant that produced them. Gene manipulation may result in the production of plants that produce seeds or fruits with higher protein content or with protein more nutritionally complete for humans. Still other plants may soon manufacture drugs for human use or have resistance to fungal and bacterial infections. Although most of these techniques of plant development are still experimental, researchers hope to be able to produce plants for market in the near future. A great agricultural revolution has begun!



Several different methods of seed dispersal have been observed in angiosperms. The seeds and fruits of some angiosperms, like those of dandelions, are carried by the wind. In other angiosperms, pressure builds inside the fruit and finally forces seeds out of the ripe fruit like bullets from a gun. The common garden plant Impatiens has fruits that spring open when touched, scattering the seeds over substantial distances.

Many fruits have coevolved with animal species that help disperse the fruits' seeds. For example, some fruits have sharp barbs that catch in fur or feathers, allowing the seeds inside to hitch rides on mammals or birds. As they move from place to place, such animals may enter a new environment. If the seeds fall off the animals and land on a spot that provides good growing conditions, they will develop into new plants. In this way, plants are carried to new environments.

Some fruits have attractive colors, pleasant tastes, and contain a variety of nutritious compounds. These fruits and the seeds inside them are eaten by mammals and birds. The fleshy, nourishing, and tasty pulp of the fruit is digested by the animal, but the seeds, which are protected by tough seed coats, are not. These seeds pass through the digestive tract of the animal without being damaged. While inside the animal, seeds may be carried over great distances. Eventually the seeds are deposited, along with a convenient dose of natural fertilizer, in a new location where they can grow.

Have you ever wondered why so many unripe fruits are green and have a bitter taste? Think about the function of fruits in relation to the evolutionary fitness of plants. Inside the unripened fruits the seeds are still maturing. If the fruits are eaten too soon, the immature seeds will not be able to grow. The plant's fitness for survival would decrease. But plants manufacture bitter-tasting compounds that they pump into fruits as the fruits develop. These bitter-tasting compounds discourage animals from eating fruits that are not ripe. The green color of unripe fruits makes it more likely that animals will not notice the fruits hidden among the green leaves of plants. When the seeds are mature, plants either remove the bitter-tasting compounds from the fruits or chemically break down the compounds completely. Plants then pump sugars into the fruits. At the same time, the fruits change color. The brightly colored fruits are more easily noticed by birds and other animals. The distribution of seeds in fruits is yet another example of plant-animal coevolution.



Figure 22–19 *The tiny seeds of the cocklebur have many hooks (top). The hooks catch onto the fur of animals and are carried to new environments. When the seeds are ripe, raspberries turn a bright red and can easily be seen by birds and other animals (bottom). After the fruits are eaten, the indigestible seeds pass through the animal and are deposited, along with other solid wastes, in a new environment.*

22–3 SECTION REVIEW

1. What is a pollinator? Why is the role of a pollinator important to seed plants?
2. Explain how plant–animal coevolution has led to the development of relationships between vector pollinators and flowers.
3. What is seed dispersal? Why is it important?
4. Explain how fruits are dispersed by animals. How does fruit dispersal contribute to seed dispersal?

LABORATORY INVESTIGATION

COMPARING RIPE AND UNRIPE FRUITS

PROBLEM

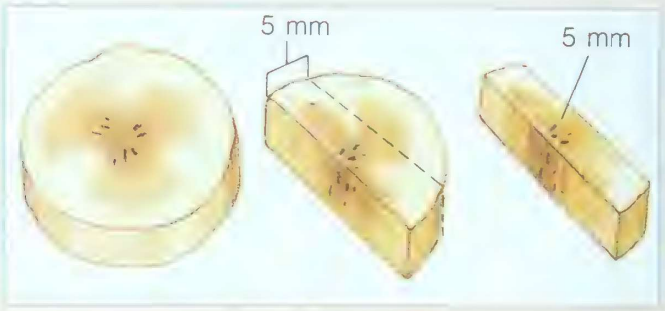
Why do fruits get ripe?

MATERIALS *(per group)*

unripe banana	hot plate
ripe banana	ruler
balance	scalpel
400-mL beaker	4 test tubes
Benedict's solution	test tube holder
sugar (dextrose) solution	test tube rack
2 100-mL graduated cylinders	hand lens
	glass-marking pencil

PROCEDURE

1. Fill a 400-mL beaker halfway with water. Place the beaker on a hot plate. Turn the hot plate on high.
2. Use a glass-marking pencil to label four test tubes. Label the first test tube *C*, for control; the second *S*, for sugar; the third, *R*, for ripe banana; and the fourth, *U*, for unripe banana.
3. Use a graduated cylinder to put 5 mL of water into the test tubes labeled *C*, *R*, and *U*. Place 5 mL of a sugar (dextrose) solution into the test tube labeled *S*.
4. With a clean graduated cylinder, add 5 mL of Benedict's solution to each of the test tubes.
5. Observe the color and appearance of the unripe banana. Peel it. Use a scalpel to cut a slice, or cross section, 5 mm thick. **CAUTION:** *Always cut away from yourself and others.*
6. Cut the slice of banana in half along its diameter. Then make a cut parallel to the diameter, about 5 mm from the cut edge, as shown in the accompanying illustration.
7. Measure the mass of the cut piece. It should have a mass of about 1 g. Put this piece of banana into the test tube marked *U*.
8. Repeat steps 5 to 7 with the ripe banana. Make sure the mass of the piece of ripe banana is the same as the mass of the unripe banana. Place this piece in the test tube marked *R*.



9. Place the test tubes in the beaker of boiling water on the hot plate. **CAUTION:** *Use the test tube holder. Place the tubes carefully.*
10. Observe the four test tubes. When the test tube that contains the sugar solution changes color, observe the color of the other test tubes.
11. Use the test tube holder to remove the test tubes from the beaker. Place the test tubes in the test tube rack. Turn off the hot plate and allow the beaker to cool.
12. Make several more slices of the ripe banana. Use a hand lens to examine the region near the center of each slice.

OBSERVATIONS

1. What did the peel of the unripe banana look like? The ripe banana?
2. In which test tubes did the greatest change occur?
3. Describe the structures you observed in the center of the banana slices.

ANALYSIS AND CONCLUSIONS

1. What do the results of the tests with Benedict's solution show?
2. What are the structures in the center of a banana?
3. How do animals help disperse banana seeds?
4. What changes occur when a banana ripens?
5. Why would an animal be more likely to find and eat ripe bananas than unripe bananas?

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

22–1 Seed Plants—The Spermopsida

- Seed plants have roots, stems, and leaves that show adaptations that enable them to perform different functions.
- Seed plants are able to reproduce without the need for standing water. Seed plants produce seeds that are able to survive periods of time that are unfavorable for growth.

22–2 Evolution of Seed Plants

- The gymnosperms are the most ancient group of surviving seed plants. The name gymnosperm means naked seed.
- The most common gymnosperms are the conifers. Conifer means cone-bearing. Most conifers produce cones, which are special reproductive organs.
- All flowering plants belong to the angiosperms. Flowers are the angiosperms' reproductive organs.
- There are two main subclasses of angiosperms: monocots and dicots. Monocots have one seed leaf; dicots have two. The veins in monocot leaves are parallel to one another. The veins of dicots form a branching network in the leaves. The flower parts of monocots occur in threes or multiples of three. The flower parts of dicots occur in fours or fives or multiples of four or five. The vascular bundles in monocots form a ring around the stem. The vascular bundles of dicots are scattered around the stem.

22–3 Coevolution of Flowering Plants and Animals

- Some flowering plants are pollinated by the wind. These plants shed vast amounts of pollen into the air.
- The process by which two organisms evolve structures and behaviors in relation to or complementary to one another is called coevolution.
- Many animals are pollinators of flowers, or agents that transfer pollen from one flower to another.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

22–1 Seed Plants—The Spermopsida
pollen grain
pollination
embryo
seed coat

22–2 Evolution of Seed Plants
scale
gymnosperm
pollen cone
angiosperm
flower
fruit
monocot
dicot
cotyledon
vascular bundle

22–3 Coevolution of Flowering Plants and Animals
coevolution
vector pollination
seed dispersal

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Flowering plants are in the class
   a. cotyledonae. c. angiospermae.
   b. gymnospermae. d. coniferae.
2. A red flower is most probably pollinated by a (an)
   a. bat. c. insect.
   b. gust of wind. d. bird.
3. Each of the following is an adaptation of plants to a life on land except
   a. tall stems. c. xylem and phloem.
   b. a waxy cuticle. d. seeds.
4. The entire male gametophyte of a seed plant is contained within the
   a. embryo. c. pollen grain.
   b. fruit. d. xylem.
5. The first seed-bearing plants were the
   a. ferns. c. conifers.
   b. mosses. d. seed ferns.
6. You examine a flower and find six petals. This flower is most likely from a
   a. monocot. c. dicot.
   b. conifer. d. fern.
7. Each of the following is a fruit except a
   a. potato. c. squash.
   b. tomato. d. strawberry.
8. Inside a seed coat, an embryo
   a. continues to grow.
   b. is kept warm.
   c. is protected from drying out.
   d. awaits fertilization.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Codevelopment is the process by which two organisms evolve structures and behaviors complementary to each other.
2. Leaves are the organs in which most plants make food.
3. Stems absorb water and dissolved nutrients from the soil.
4. Phloem carries water up a plant stem.
5. A flower that smells like rotten meat most likely attracts birds for pollination.
6. The process of distributing seeds away from the parent plant is called seed dispersal.
7. A plant whose leaf veins form a branching network is most probably a dicot.
8. Bees gather nectar while flying.

Word Relationships

A. *An analogy is a relationship between two pairs of words or phrases generally written in the following manner: a:b::c:d. The symbol : is read "is to," and the symbol :: is read "as." For example, cat:animal::rose:plant is read "cat is to animal as rose is to plant."*

In the analogies that follow, a word or phrase is missing. Complete each analogy by providing the missing word or phrase.

1. gymnosperm:cones::angiosperm:_____
2. fruit:seeds::cones:_____
3. xylem:water::phloem:_____
4. ferns:spores::conifers:_____

B. *In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.*

5. net veins, parallel veins, one cotyledon, nine petals
6. bee, bird, bat, wind
7. strawberry, blueberry, apple, potato

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. What is seed dispersal? How does it contribute to the survival of a plant species?
2. What is a cotyledon?
3. How do seed plants help humans survive?
4. Why do botanists consider a tomato and a squash fruits?
5. How do roots and vascular tissues contribute to a redwood tree's great size?
6. How are seed plants better able to survive drier conditions than mosses and ferns?
7. What is a conifer? How does a conifer differ from an angiosperm?
8. What is wind pollination? How does wind pollination differ from vector pollination?
9. Why is it important that seeds provide food for the embryo plant?

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** In nature, flowers have a limited range of colors. In a garden, however, flowers can have many more colors. Apply your knowledge of pollination and artificial selection to explain why.
2. **Making predictions** In a time in the future, a terrible fatal disease is found to affect all monocots. Predict the effect of this disease on the human population.
3. **Relating cause and effect** Scientists invent a new insecticide that can kill all the insects in the world. What important harmful effect would this have on plants?
4. **Interpreting diagrams** Examine the plant in this photograph. How many cotyledons would the seeds of this plant have? Explain your reasoning.



5. **Applying concepts** A farmer decides not to plant her fields one year. Later in the year heavier than normal rains fall on the field. Now the farmer wishes she had planted her crops. Why do you think she changed her mind?
6. **Applying concepts** Making a cut through the bark of a tree in a complete circle around the trunk often results in the death of the tree. Using your knowledge of vascular tissue, explain why this might happen.
7. **Relating facts** The seeds of a gymnosperm are probably not likely to be dispersed by animals, whereas the seeds of angiosperms are likely to be dispersed by animals. Explain why this is so.
8. **Using the writing process** Suppose all gymnosperms died out tomorrow. Write a story that details ways in which your life would be changed.