3

Plant Anatomy

Purpose and Expected Outcomes

This chapter is designed to describe the physical and structural organization of higher plants and to show how plant anatomy is used as a basis of classifying horticultural plants.

After studying this chapter, the student should be able to

1. Describe the levels of eukaryotic organization.
2. Describe the cell structure and function of major organelles.
3. List and describe the primary tissues of higher plants and their functions.
4. Describe various plant organs and how they are used as a basis for classifying horticultural plants.

[COLOR PLATES—*see color plate 3* for additional chapter photos]

Overview

Plant Anatomy
The study of the structure of cells, tissues, and tissue systems.

The scientific discipline of **plant anatomy** deals with cataloging, describing, and understanding the function of plant structures. The functional aspect of the study of anatomy overlaps with *plant physiology* (Chapter 5). Plant anatomy can be studied at various levels of eukaryotic organization, the most fundamental being the molecular level, which deals with macromolecules (Figure 3–1). These basic molecules are organized into *organelles*. The next level of complexity of organization is *tissues*. Cellular substructures are not visible to the naked eye, requiring the aid of magnifying instruments to be seen. Even though organs and whole-plant structures are the most readily visible to the naked eye, it is important to know that what we see are products of subcellular function involving the effects of physiological processes.

A good understanding of plant anatomy helps horticultural scientists in manipulating plants for increased productivity and aesthetic value. Before nudging nature, one needs to know and understand the norm, how it responds to change, and how to effect change.

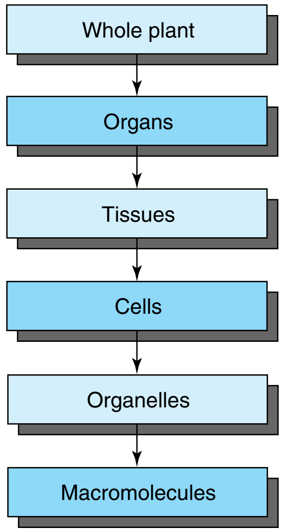


FIGURE 3–1 Levels of organization of eukaryotes. The study of eukaryotes below the level of organs usually requires the aid of special equipment such as microscopes to observe and manipulate.

3.1 Cell

3.1.1 THE UNIT OF ORGANIZATION OF LIVING THINGS

Cell
The basic structural and physiological unit of plants and animals.

The **cell** is the unit of organization of living things. Some organisms have only one cell *(unicellular),* and others are made up of many cells *(multicellular).* Unicellular organisms are also called *prokaryotes,* or lower organisms, an example being the algae. They lack a distinct nucleus because of the absence of a nuclear membrane. Higher organisms, or *eukaryotes,* have distinct nuclei and cells that are compartmentalized by means of membranes such that each compartment has a different function. They may be unicellular or multicellular. Plants of horticultural interest are eukaryotes, or higher plants.

Under appropriate laboratory conditions, a single cell may be nurtured to grow and develop to produce the entire plant from which it was derived. This capability is called *totipotency* and results because each cell has the complete *genome* (the complete set of genes for the particular organism) to direct the development of the whole plant. This capacity is exploited in propagating certain horticultural plants and manipulating the genetic structure of others to produce new and improved types.

Differentiation
Physical and chemical changes associated with the development and/or specialization of an organism or cell.

Cells, like all living things, grow and age. There are different sizes and shapes of cells. Through the process of *cell division,* a single cell rapidly divides and multiplies to produce a uniform mass of cells. These cells subsequently undergo changes through the process of **differentiation** to perform specific functions in the plant, as needed. For example, some cells change to produce strengthening tissues, while others produce flower or leaf buds. During this differentiation process, the shapes and sizes of cells are modified appropriately, as is their structural strength. Horticultural products are harvested in time to obtain products that have the optimal quality desired by consumers. A delay in harvesting a product may reduce its quality and consequently the market value. As cells age, their physical structures change such that products that should be juicy and succulent, for example, become less juicy and more fibrous.

3.1.2 CELL STRUCTURE

Plasma Membrane
The membrane that surrounds the entire protoplast.

The plant cell may be divided into three parts—the *outer membrane* (**plasma membrane** or *plasmalemma*), the *cytoplasm,* and the *nucleus.* The plasma membrane functions as a selective barrier to the transport of substances into and out of the protoplast.

Organelle
A specialized region in a cell that is bound by a membrane.

The content of a living plant cell, excluding the wall, is called the protoplasm (or protoplast). Embedded in the protoplasm are discrete bodies called **organelles.** The most prominent of cellular organelles is the nucleus, the *organelle* that houses most of the cell's genetic material (deoxyribonucleic acid, or DNA). DNA is responsible for directing cellular functions. Some old cells lack nuclei. The area outside of the nucleus is called the cytoplasm, and it contains the other organelles (Figure 3–2). Some of these organelles are described in the following sections.

The Cell Wall

All plant cells except the sperm and some egg cells have walls. When the protoplast dies and degenerates, what is left is the *cell wall,* which constitutes the bulk of woody plants. Chemically, the cell wall consists of *cellulose, hemicellulose, protein,* and *pectic substances.* Cellulose, the most abundant cell wall component, is a polysaccharide (a polymer of sucrose molecules) and nutritionally of little value to humans since it is not digestible. Pectins are acidic polysaccharides (polymers of galacturonic acid). At a particular stage in the life of a cell, deposition of *lignin*, a complex mixture of polymers of phenolic acid occurs. This hardens the cell wall, rendering it rigid and inelastic. This process is called *lignification.*

The thickness and other structural features of a cell wall vary according to the age and type of cell. All cells have a standard *primary cell wall,* which is the first to form when a cell is developing. This type of cell wall is found where cells are actively growing and dividing. Chemically, it is composed predominantly of cellulose and pectic substances. When cell growth ceases, a *secondary cell wall* is deposited inside of the primary cell wall. With this new layer of cellulose and lignin, the cell wall becomes rigid. Adjacent cell walls are held together by a pectin-rich material called the *middle lamella.* When fruits rot under fungal attack, the middle lamella breaks down into the characteristic slimy fluid associated with rotting. Cell-to-cell interconnections are produced by cytoplasmic strands called *plasmodesmata*.

Nucleus

Upon staining a cell in the resting stage (interphase), the *nucleus* usually shows up as a spheroidal and densely stained body. This structure is the fundamental organelle of a cell since it is the primary repository of genetic information for the control and maintenance of cellular structure and function. The nucleus is composed of DNA,

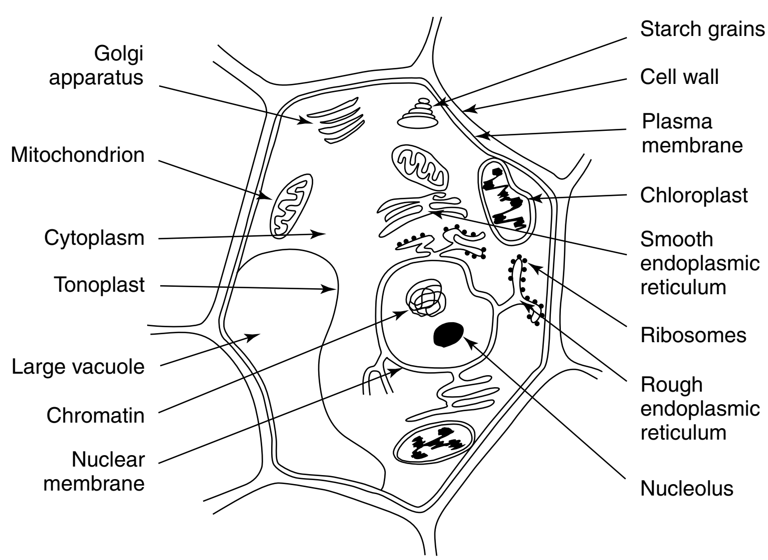


FIGURE 3–2 The parts of a plant cell.

ribonucleic acid (RNA), proteins, and water. The DNA occurs in defined structures called **chromosomes** that allow it to be replicated accurately (except in occasional alterations called *mutations*).

Chromosome
A highly organized nuclear body that contains DNA.

Chromosomes are visible as strands when the DNA-histone complex coils and appears to condense. Chromosomes stain differentially to reveal dark and light sections. The dark sections are called *heterochromatin* and represent DNA-containing genes that are not actually directing the synthesis of RNA. The light-staining sections are called *euchromatin* and contain active genes. The chromosome number per cell is characteristic of the species (Table 3–1). The number of chromosomes in the *gametic cell* (sex cell, such as pollen) is half that of the *somatic cell* (body cell). When two *homologous pairs* (identical mates) occur in a cell, it is called a *diploid.* Sometimes, in certain plant species, cells may contain multiple copies beyond the diploid number, a condition called *polyploidy*.

Vacuoles

Vacuoles are cavities in cells that contain a liquid called the *vacuolar sap,* or *cell sap,* within the vascular membrane called *tonoplast.* The sap consists mainly of water, but other substances such as salt, sugars, and dissolved proteins occur, according to the physiological state of the cell. Vacuoles also store water-soluble pigments called *anthocyanins.* These pigments are responsible for the red and blue colors of many flowers (e.g., geranium, rose, and delphinium), fruits (e.g., cherry, apple, and grape), and vegetables (e.g., cabbage, turnip, and onion). Anthocyanins are also involved in the fall colors of some leaves. Vacuoles vary in size: In meristematic cells (young and actively dividing), the vacuoles in a single cell are small in size but numerous. In mature cells, however, these numerous small vacuoles usually fuse into large cavities that may occupy about 90 percent of the cell, pushing the remainder of the protoplasm against the cell wall. Vacuoles absorb water to create the **turgor pressure** required for physical support in plants. Plants under moisture stress wilt for lack of turgor pressure. A variety of rapid movements in plants such as flower opening, leaf movement in response to touch (e.g., in *Memosa pudica*), and the opening and closing of guard cells are attributed to functions of the vascular vacuoles. Vacuoles have some digestive functions similar to those of lysosomes in animal cells; macromolecules are broken down in vacuoles and their components recycled within the cell.

Turgor Pressure
The pressure on a cell wall that is created from within the cell by the movement of water into it.

TABLE 3–1 The Number of Chromosomes Possessed by a Variety of Plant Species

Species	*Scientific Name*	*Chromosome Number (n)*
Carrot	*Daucus carrota*	18
Garden pea	*Pisum sativum*	7
Evening primrose	*Oenothera biennis*	7
Broad bean	*Vicia faba*	6
Potato	*Solanum tuberosum*	24
Snapdragon	*Antirrhinum majus*	8
Tomato	*Lycopersicon esculentum*	12
Corn	*Zea mays*	10
Lettuce	*Lactuca sativa*	18
Garden onion	*Allium cepa*	8
White oak	*Quercus alba*	12
Yellow pine	*Pinus ponderosa*	12
Cherry	*Prunnus cerasus*	16
Bean	*Phaseolus vulgare*	11
Cabbage	*Brassica oleracea*	9
Cucumber	*Cucumis sativus*	7

Plastids

Plastid
An organelle that is bound by a double membrane and associated with different pigments and storage products.

Plastids are very dynamic plant cell organelles capable of dividing, growing, and differentiating into different forms, each of which has a different structure and function. Plastids contain their own DNA. They are said to be *semiautonomous* because they synthesize some of their own proteins. The genes they contain are not inherited according to Mendelian laws (they have extrachromosomal inheritance, meaning that it does not occur in chromosomes in the nucleus). *Chloroplasts* are plastids that contain *chlorophyll,* the green pigment that gives plants their characteristic green color and, more importantly, is involved in photosynthesis. A chloroplast contains saclike vesicles called *thylakoids,* which are stacked in units called *grana* (singular: *granum*). The grana are suspended in a fluid called *stroma.* Chloroplasts occur only in plants, not in animals. During cell division, no special mechanism ensures equal distribution of plastids. Consequently, certain cells may receive no plastids at all; the parts of the leaf that have cells without chloroplasts develop no green color. Instead, they produce white, pink, or purple coloration. Leaves showing such patches of color are said to be *variegated* (Figure 3–3). Colorless plastids are generally called *leucoplasts.*

Whereas nonangiosperms are generally not colorful, being predominantly green, angiosperms (flowering plants whose seeds develop within ovaries that mature into fruits) have certain plastids with the capacity to produce large amounts of *carotenoids* (bright yellow or orange and red pigments). These plastids are called *chromoplasts* (*chroma* means color). More than 30 different types of pigments have been found in the chromoplasts of pepper (*Capsicum* spp.). The pigments are diverse in their composition and in the colors they produce. Flowers display a spectacular array of colors. Colors found in petals and fruits are caused by plastids. Although leaves are predominantly green, they may also exhibit other colors. The presence of chlorophyll overwhelms other colors and masks their expression; however, under the right conditions (such as occurs seasonally in fall), the chlorophyll breaks down, allowing the masked colors to be expressed as beautiful colors during the fall season in temperate regions. All types of plastids, especially chloroplasts and chromoplasts, are interconvertible. When plants are grown in darkness, chloroplasts change into *etioplasts,* resulting in a deformation called *etiolation* (spindly growth due to excessive elongation of internodes). Light is required to reverse this abnormal growth. To prevent etiolation, plants grown under conditions of insufficient daylight (such as houseplants and greenhouse plants) are provided with supplemental light from an artificial source.

Mitochondria

A cell may survive without plastids, but all cells must have *mitochondria,* organelles that provide the energy (adenosine triphosphate, ATP) required for plant processes. These organelles are bound by a double membrane. The inner membrane is folded into projections

FIGURE 3–3 Variegation of the leaf of dumbcane (*Dieffenbachia* spp.). *(Source: George Acquaah)*

called *cristae;* this extreme folding increases the internal surface area of mitochondria for biochemical reactions. Mitochondria have their own DNA, just like chloroplasts. They are sites of respiration, the cellular process responsible for producing energy for living organisms.

Ribosomes

Ribosomes are sites of protein synthesis. These tiny structures consist of approximately equal amounts of RNA and protein. Ribosomes may occur freely in the cytoplasm or attached to the endoplasmic reticulum (described next). When engaged in protein synthesis, ribosomes tend to form clusters called *polyribosomes* or *polysomes.*

Endoplasmic Reticulum

The *endoplasmic reticulum* is a membranous structure distributed throughout the cytoplasm as a system of interconnected, flattened tubes and sacs called *cisternae.* The extent of folding and the amount of endoplasmic reticulum depend on the cell type and function and the cell's stage of development. A transverse section of this organelle shows two parallel membranes with a space between them. When ribosomes are attached to the surface, it is called *rough endoplasmic reticulum;* otherwise it is called *smooth endoplasmic reticulum.* This organelle also serves as a channel for the transport of substances such as proteins and lipids to different parts of the cell and as the principal site of membrane synthesis.

Golgi Apparatus

The *Golgi apparatus* is a collective term for structures called *Golgi bodies* or *dictyosomes,* which consist of a stack of about four to eight flattened sacs, or cisternae. In higher plants, dictyosomes have secretory functions. They secrete new cell wall precursors and other substances.

Microbodies

Microbodies are single-membraned, spherical bodies that have roles in metabolic processes. A group of microbodies associated with mitochondria and chloroplasts are called *peroxisomes.* These microbodies contain the enzyme glycolate oxidase and function in glycolate oxidation during photorespiration (light-dependent production of glycolic acid in chloroplasts and its subsequent oxidation in peroxisomes). Another group of microbodies called *glyoxysomes* contain enzymes involved in the breakdown of lipids to fatty acids. The fatty acids are converted to carbohydrates that are used for growth and development during the germination of many seeds.

Ergastic Substances

Ergastic substances are miscellaneous substances in the cell that include waste products and storage products such as starches, anthocyanin, resins, tannins, gums, and protein bodies. These substances may be classified as either *primary metabolites* (e.g., starch and sugars that have a basic role in cell metabolism) or *secondary metabolites* (e.g., resins and tannins that have no role in primary metabolism). Secondary metabolites are known to play a role in protecting the plant from herbivores and insect attack. Tannins are toxic to animals. For example, the rhubarb leaf blade contains calcium oxalate crystals, but the petiole does not; thus, while the petioles are edible, the leaf blade is toxic to animals. Similarly, *Philodendron* stems and shoots and *Dieffenbachia* (dumbcane) leaves contain calcium oxalate in the raphides (sharp needles on the plant) that is very irritating to the throat. Noncrystalline ergastic substances such as silica deposits occur in the cell walls of some grasses and sedges. These deposits strengthen the tissue and also protect the plant against insects and other pests.

3.2 Types of Plant Cells and Tissues

Tissue
A set of cells that function together.

Different types of cells are used to construct the different tissues and organs to meet the variety of functional needs of the plant. These cells can be classified into three basic types: *parenchyma, collenchyma,* and *sclerenchyma.* The three types of cells differ from each other in their cell wall characteristics. Simple cells aggregate in certain characteristic patterns to form **tissues.** When the tissue consists of one type of cell, it is described as a *simple tissue;* when more than one type of cell is present, the tissue is called a *complex tissue.*

3.2.1 SIMPLE TISSUES

Meristem
A cell or region of specialized tissue whose principal function is to undergo cell division.

1. *Parenchyma.* Parenchyma cells are characterized by their thin wall. The tissue they form is described as *parenchyma (parenchymatous) tissue.* This cell type occurs extensively in herbaceous plants. Functionally, parenchyma cells are found in actively growing regions of plants called **meristems**. Meristematic cells are undifferentiated. The parenchyma cells in meristematic regions are also called *meristematic parenchyma.* Some parenchyma cells have synthetic functions, such as in the chloroplasts, where they are called *photosynthetic parenchyma,* or *chlorenchyma* cells, and function in photosynthesis. Some parenchyma cells have secretory roles and are called *secretory parenchyma.* The fleshy and succulent parts of fruits and other swollen parts such as roots and tubers consist of large amounts of parenchyma tissue.
2. *Collenchyma.* Collenchyma cells have a thick primary wall that plays a mechanical role in the plant support system by strengthening tissues. This role is confined to regions of the plant where active growth occurs so as to provide the plant some protection from damage. Collenchymatous tissue occurs in the stem below the epidermis (outermost layer of the cells in the particular plant part) in leaves, it occurs in the petiole (or leaf stalk), leaf margins, and main veins of the leaf blade or lamina. Fruit rinds that are soft and edible contain collenchyma tissue. As these cells age, they accumulate hardening substances and become unevenly sclerified, or thickened.
3. *Sclerenchyma.* Sclerenchyma cells have two walls, primary and secondary, the latter being thicker. They also have a mechanical function in plants, serving as reinforcement for tissues. Sclerenchyma cells have elasticity and resiliency and thus can bend without snapping. Naturally, therefore, they are found in places in the plant, such as the leaf petiole, where bending and movement occur. There are two basic types of sclerenchyma cells—short cells, called *sclereids,* and long cells, called *fibers.* The primary cell wall is made up of cellulose, hemicellulose, and other pectic substances. The secondary wall is formed from large deposits of lignin; cells with deposits of lignin are said to be lignified. Sclerenchyma occurs, for example, in the stones of fruits, around the seeds, or in immature fruits. Sclerenchyma cells abound in plants that yield fiber such as kenaf, flax, and hemp.

3.2.2 COMPLEX TISSUES

The three basic cell types may aggregate separately or in combination to form complex tissues that perform a variety of functions in the plant. Some of these tissues are *epidermis, secretory tissue,* and *conducting tissue.*

Epidermis
The outermost layer of cells on all parts of the primary body—stems, leaves, roots, flowers, fruits, and seed—but absent from root tips and apical meristems.

Epidermis

The **epidermis** is the outermost layer of the plant that separates its internal structures from its external environment. Since a plant's environment changes, its epidermis should possess developmental plasticity or flexibility such that it adapts to a wide range of conditions. Such flexibility may involve physiological, structural, and anatomical variability.

By virtue of its position, the primary function of the epidermis is to regulate water and gas movement into and out of the plant. Some plants have a waterproof epidermis, whereas others are permeable to moisture and gases. Waterproofing is caused by the occurrence of a hydrophobic (water-repelling) substance called *cutin* (polymerized fatty acids) that is deposited on the outside of the epidermal wall. Waterproofing occurs in most rain forest epiphytes, such as cactus, orchid, and philodendron, where protection against leaching of minerals is critical. The resulting layer is called a *cuticle* and is waxy in nature. The epidermis protects the plant against sunlight. Intense sunlight can overheat the protoplasm and bleach the chlorophyll. Sometimes orchardists paint the exposed trunks of fruit trees to reflect sunlight and thus prevent damage from excessive heat. The epidermal layer also has a protective role, resisting the intrusion of biological pests such as bacteria and fungi. Some layers protect the plant against chewing insects, and others have hairlike structures (pubescence) called *trichomes* that interfere with oviposition (deposition of eggs). Some of these epidermal outgrowths **secrete** a variety of substances for many different purposes.

Secretion
The movement, either by diffusion or active transport, of materials out of a plant or into a space where they can accumulate for storage.

In the green parts of plants, especially in leaves, the epidermis has pores called *stomatal pores,* or *stomata* (singular: *stoma*). The pores occur predominantly on the abaxial (lower surface) part of the leaf and are bordered by structures called *guard cells.* The guard cells control the opening of the stoma. These pores function in gaseous and moisture exchange. In some horticultural practices, certain chemicals are administered to plants by foliar application. Such chemicals enter the plant through the stomata.

Secretory Tissue

According to the nature of the material secreted, secretory systems may be classified according to where they are found (i.e., whether outside or inside of the plant).

Found Outside of the Plant

1. *Nectaries.* Nectaries are found on parts of the plant. When they occur in flowers they are called floral nectaries, and when they occur elsewhere they are called extrafloral nectaries. They secrete a fluid called *nectar* that consists of sugars (especially glucose, sucrose, and fructose) and numerous other organic compounds. Certain insects including butterflies and bees feed on nectar and in the process aid in the pollination of the flowers.
2. *Hydathodes.* Secretory structures called hydathodes secrete almost pure water. They are thus thought to play a role in the transport of minerals to young tissues, in addition to the role played by transpiration. Under conditions of moist soil, high humidity, and cool air, the leaves of many plants, especially grasses, are known to produce droplets of water along their margins that appear similar to dew. However, the moisture is due to a special secretory process called *guttation*.
3. *Salt glands.* Salt glands, which secrete inorganic salts, occur in plants that grow in desert and brackish areas that are high in salts. These salts may accumulate on the leaves of certain plants and thereby make them unattractive to herbivores.
4. *Osmophores.* Osmophores are fragrance-secreting glands found in flowers. They secrete odors and perfumes (predominantly oily compounds belonging to the class of volatile, small terpenes). The repulsive odor of aroids is attributed to the amines and ammonia produced by osmophores.
5. *Digestive glands.* Digestive glands are found in insect-eating (insectivorous) plants. They secrete enzymes used in digesting the animal materials trapped by such plants (e.g., pitcher plant).
6. *Adhesive cells.* Adhesive cells secrete materials that allow for attachment between host and parasite. The strong attachment due to adhesive material helps parasites during penetration of their host.

Found Inside of the Plant

1. *Resin ducts.* Resin ducts are long canals that contain sticky resin. They are most abundant in the wood and leaves of conifers.
2. *Mucilage cells.* Mucilage cells are slimy secretions high in carbohydrate and water content. The mucilage secreted by the growing root tip, called mucigel, is believed to be important in lubricating the passage of the root through the soil.
3. *Oil chambers.* Certain glands secret compounds that are commonly deposited in large cavities in the plant. However, these oils are moved outside of the plant, where they are aromatic.
4. *Gum ducts.* Cell wall modification results in the production of gums in certain tree species.
5. *Laticifers.* Laticifers are latex-secreting glands. They occur in species such as milkweed, poppy, and euphorbia. The latex may contain diverse compounds including carbohydrates, lipids, tannins, rubber, protein, and crystals. Even though the secretion from poinsettia *(Euphorbia pulcherrima)* has been found to be nontoxic to humans, "plant milk" should not be ingested.
6. *Myrosin cells.* Myrosin cells contain a neutral enzyme called myrosinase. However, when this harmless protein is mixed with its substrate (thioglucosides), a toxic mustard oil (isothiocyanate) is produced. This mixing occurs when myrosin cells are ruptured during chewing by insects or other animals.

Since all cells are capable of transporting materials across their boundaries, all cells may be said to have secretory functions. Secretory functions are needed by cells for a variety of reasons. Accumulation of metabolic waste in the cell may be toxic, and so the waste must be excreted. Compounds that are actively transported out of the cell include sugars, inorganic salts, hormones, nitrogenous compounds, and sulfur-containing compounds. However, deposits in the cell wall such as cuticle, suberin, lignin, and waxes are products of secretory activities that are desired for specific roles in the plant, as previously mentioned. In carnivorous plants, secretions are needed to digest trapped animals.

Apart from secretory activities that are related to cellular metabolism, cells secrete other chemicals. Some glands in flowering plants secrete scents to attract pollinators. Some flowers produce very sweet fragrances that people enjoy. Other plant secretions are substances that repel animals that may be pests.

Conducting Tissues

Vascular Plant
Any species that has vascular tissue—xylem and phloem.

Vascular plants have an elaborate system of vessels used in conducting organic and inorganic solutes from place to place in the plant. These systems are complex tissues consisting of a variety of cell types. There are two conducting tissues in plants: *xylem* and *phloem.*

Xylem Tissue The xylem tissue conducts water and solutes from the roots up to the leaf, where food is manufactured by the process of photosynthesis. Since it consists of sclerenchyma cells, it also provides structural support to the plant as a whole, and it stores nutrients or new materials for photosynthesis. The conducting cells of the xylem are of two types, *tracheids* and *vessel elements.* These two types of cells are collectively called *tracheary elements,* which vary widely in size, shape, and types of secondary walls.

Water is moved up the xylem tissue by water potential. This movement is caused by passive transport because the xylem cells have no protoplasm, just the cell wall, and hence function essentially as dead cells. Tracheids tend to be long and spindle shaped; vessel elements may be narrow or wide. Both cell types have lateral perforations (or *pits*) to permit flow of cell sap from cell to cell. The elements may have large holes in the primary wall and thus are classified as tracheids, or they may lack such holes and be called vessel elements. Tracheids are the only conducting elements in gymnosperms. In angiosperms, vessel elements are good conductors when water is abundant and flows in high volume. Wood is predominantly xylem tissue. In nonwoody (herbaceous) plants, xylem occurs in amounts necessary for the conduction of water.

Phloem Tissue Structurally, phloem tissue may be made up of parenchyma cells or a combination of parenchyma and sclerenchyma cells. The conducting elements are called *sieve elements* and are of two types, *sieve cells* (primarily parenchyma) and *sieve tube members*. In angiosperms, sieve elements are closely associated with spindle cells called *companion cells.* In nonangiosperms, these cells are called *albuminous cells.* They are believed to be involved in *phloem loading* (in which newly synthesized sugars are loaded for export to other plant parts). This loading occurs in the minor veins of leaves. Phloem cells, of necessity, function as living cells. The general function of phloem tissue is to move food from the leaves, where it is manufactured, to other parts of the plant, where it is used or stored. A significant difference between xylem and phloem tissue function is that the plant actively controls the distribution of photosynthates as conducted by the phloem tissue system but has a passive role in the movement of raw materials up to the leaves. The active (under the plant's control) movement of food by plants enables food to be transported to the parts of the plant where it is needed and similarly be extracted in other areas (*source-sink* relationship). This dynamic nature of the movement of sugars, amines, and other nutrients enables the plant to reallocate resources as it grows through various phases. Phloem cells are not durable and must be replaced constantly.

Apical Meristems

In animals, growth occurs by means of the *diffuse growth* process. In this process, growth occurs throughout the entire individual, all parts growing simultaneously. In plants, however, the means of growth is by the *localized growth* process, whereby growth is limited to certain regions called meristems.

Meristems are areas of active growth where cells are dividing rapidly. The cells in these regions are undifferentiated (sources of *developmental plasticity*). In organs, such as the root and the shoot, the meristems are located at the tip (apex) and hence are called *apical meristems*. Some meristematic cells occur in the leaf axil and are called *axillary meristems*. Meristems also occur in other parts of the plant (e.g., *basal, lateral,* and *intercalary*). The localized growth process makes it possible for juvenile and mature adult cells to coexist in a plant provided good environmental conditions exist. The plant can continue to grow while certain organs and tissues are fully mature and functional and can grow indefinitely without any limit on final size. This growth pattern is called *open* or *indeterminate.* In reality, many plants appear to have predictable sizes that are characteristic of the species, but this feature is believed to be largely an environmental and statistical phenomenon. Under controlled environmental conditions in which optimal growth conditions prevail, many annual plants have been known to grow perennially.

In some species, the apical meristem dies after it has produced a certain number of leaves. The plant then ceases to grow and is said to be *determinate* (as opposed to indeterminate). In flowering species, plants go through a vegetative growth phase of variable duration (depending on the species) before flowering.

3.3 Stem

The *stem* is the central axis of the shoot of a plant.

3.3.1 FUNCTIONS

The functions of the stem include the following:

1. Stems produce and provide mechanical support for holding up the branches, leaves, and reproductive structures. Leaves of plants need to be displayed such that they intercept light for photosynthesis.

2. Stems move water and minerals through their conducting vessels up to the leaves for the manufacture of food and then conduct manufactured food down from the leaves to other parts of the plant.
3. Stems may be modified to serve as storage organs for food, water, and minerals. Succulents such as cacti have stems that are designed for storage. The Irish potato is a swollen stem.
4. Certain plants are propagated through asexual means by using pieces of the stem as cuttings. These cuttings are rooted and then planted as seedlings to raise new plants.

3.3.2 STEM TYPES

There are two basic types of stems in vascular plants: *dicots* (*dicotyledons,* or two cotyledons) and *monocots* (*monocotyledon,* or one cotyledon). They differ in how the primary tissues (xylem and phloem) are arranged. The outermost layer of the stem is the *epidermis,* which borders the internal part called the *cortex.* The cortex is usually composed predominantly of parenchyma cells. It may contain sclerenchyma cells in some plants. The cortex is usually narrow, except in herbaceous stems of monocots, in which it is often extensive. The cortex surrounds the *vascular tissues,* which form a central cylinder called the *stele.* The stele consists of *vascular bundles* and is made up of xylem and phloem tissues. In dicots and gymnosperms, vascular bundles are arranged in a ring (Figure 3–4). In the center of the stem lies a region of purely parenchyma cells called the *pith.* In monocots, the bundles are distributed throughout the cortex, and there is no pith (Figure 3–5).

3.3.3 MODIFIED STEMS

Stems do not always grow upright or vertically. Other forms of stems occur either above or below ground.

1. *Crowns.* The crown may be likened to a compressed stem, as found in bulbs. Leaf and flower buds occur on the crown and give rise to leaves and flowers. In plants such as asparagus, the crown may be further modified into a food storage organ.
    a. Plants with modified or specialized underground storage organs are called bulbous plants. There are different types of these plants—true bulbs, corms, crowns, tubers, rhizomes, stolons, pseudobulbs, and tuberous roots. These structures are further discussed in Chapter 10 (vegetative propagation).

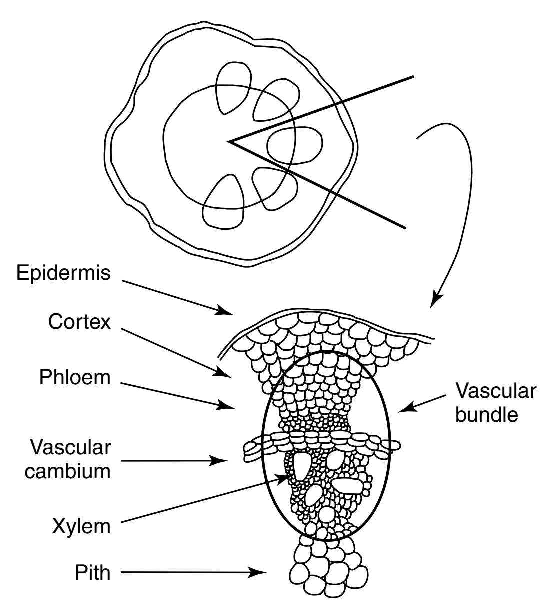


FIGURE 3–4 A cross section of a dicot stem.

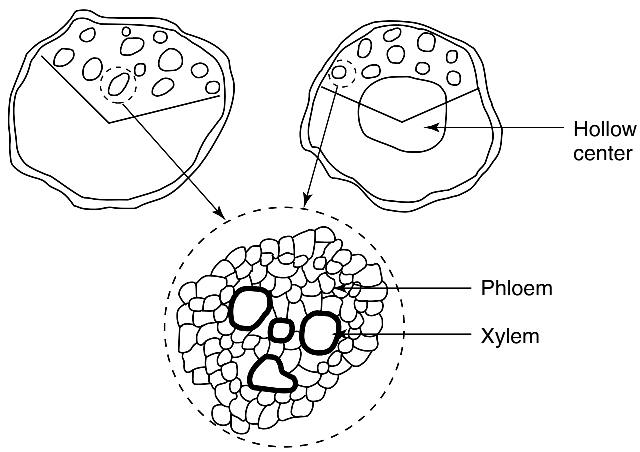


FIGURE 3–5 Cross sections of monocot stems: (a) a stalk and (b) a culm with a hollow center. A corn plant has a stalk and a bamboo has a **culm**.

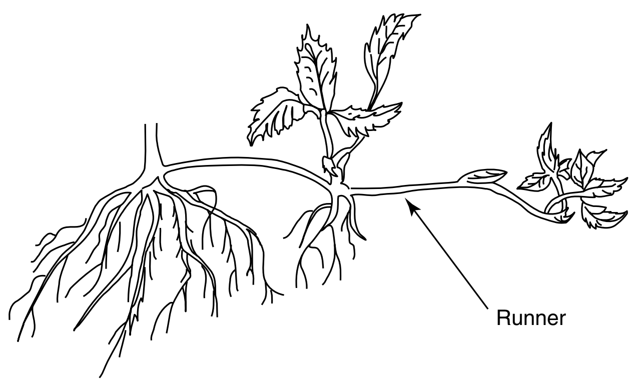
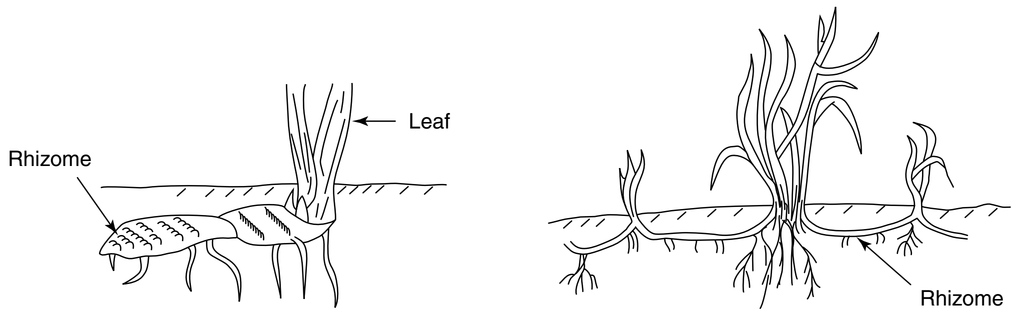


FIGURE 3–6 Runner of strawberry.

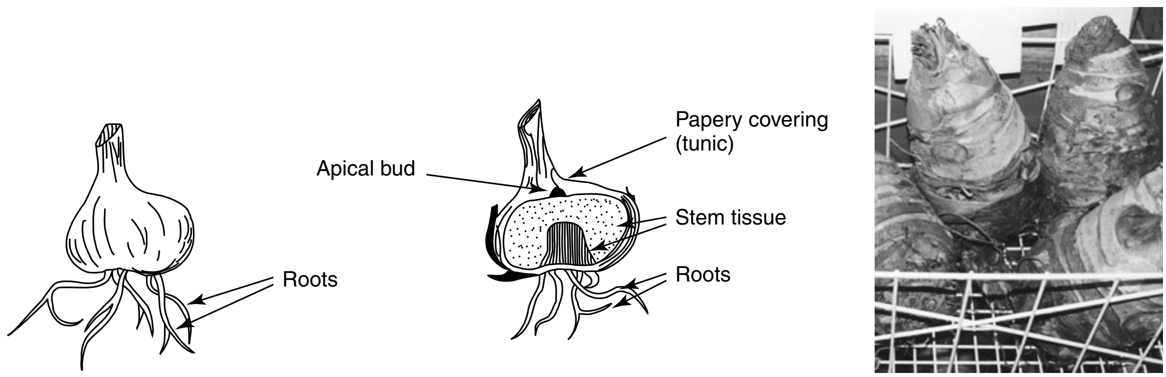
2. *Stolons.* Stolons are stems that grow horizontally above ground and occur in plants such as strawberry and Bermuda grass (Figure 3–6). Roots may arise at the nodes of the stem as it creeps on the surface of the soil. When stolons have long internodes that originate at the base of the crown of the plant (as in strawberry), the stolon is called a *runner.*
3. *Spurs.* Spurs are found on branches of woody plants such as pear and apple. They are stems whose growth has been severely restricted due to shortened internodes. Spurs may resume normal growth at a later stage.
4. *Rhizomes.* Plants such as bamboo, banana, and canna produce horizontally growing underground stems called rhizomes (Figure 3–7). Most rhizomatons species are monocots. Rhizomes differ in size, as in the species ginger *(Zingiber officinale),* in which they perform storage functions.
5. *Corms.* Corms are underground structures that are compressed and thickened stems (Figure 3–8). They occur in only some monocots. Ornamentals including crocus and gladiolus produce corms. Corms are not true bulbs. They comprise a solid stem with distinct nodes and internodes, covered by dry, scale-like leaves. Corms produce roots for anchorage and to pull the corm deeper into the ground, and a set of fibrous roots for water and nutrient absorption. They also produce branches called *cormels* that can be used for propagation.
6. *Bulbs.* Like corms, bulbs have compressed stems (based plates). They are so highly compressed that the prominent part of the structure is not the stem but rather modified leaves that are attached to the stem and wrapped up into a round

Culm
Stem of grasses and bamboos, usually hollow except at the swollen nodes.

FIGURE 3–7 Rhizomes. These underground structures differ in size and may be significant storage organs of the plant where they are thick, as in ginger *(Zingiber officinale)*.

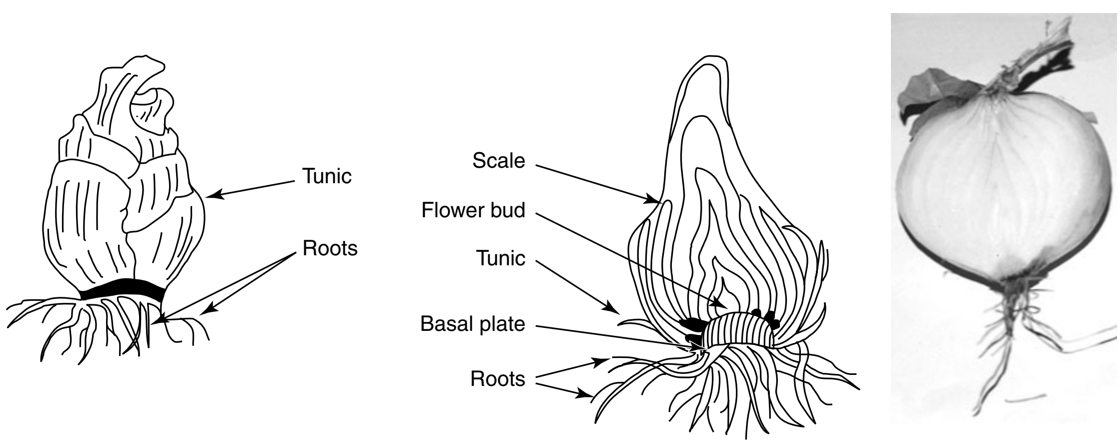


(a) Thick rhizome (b) Thin rhizome



(a) Whole corm (b) Vertical section (c) Whole corm

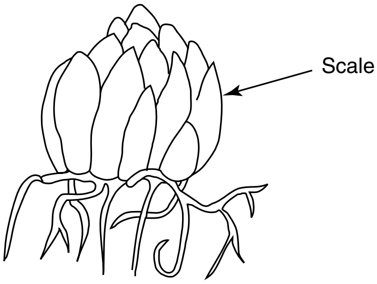
FIGURE 3–8 A corm. *(Source: George Acquaah)*



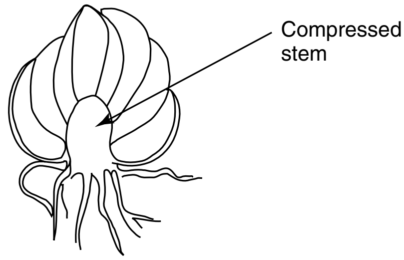
(a) Whole bulb (b) Vertical section (c) Section of whole bulb

FIGURE 3–9 Tunicate bulb.

structure called a bulb. These scale leaves store food. Plants including tulip, lily, onion, and hyacinth produce bulbs. Unlike corms, bulbs lack distinct nodes and internodes. There are two basic types of bulbs. A bulb is described as tunicate (as in onion) when the modified leaves completely cover the stem in concentric layers with addtional protective tunic that dries up into a relatively thin membrane upon harvesting. Bulbs like iris, tulip, and hyacinth are described as cold-hardy and planted in the fall season to flower in springtime. Others like *Amarylis* and *Hymerocallis* are tender bulbs that are planted in summer. Bulbs produce side branches called bulblets or offsets that are used as propagules (Figure 3–9). In Easter lily, the attachment of the leaves is only partial, not concentric, and irregular. This type of bulb is called a scaly bulb and lacks a protective tunic. They are more prone to damage and dessication (Figure 3–10).



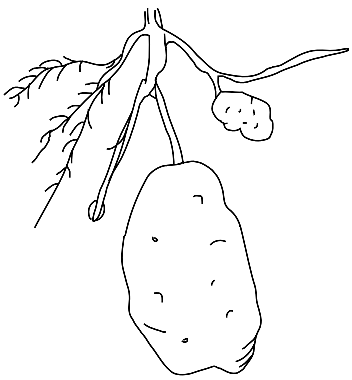
(a) Whole bulb



(b) Cross section

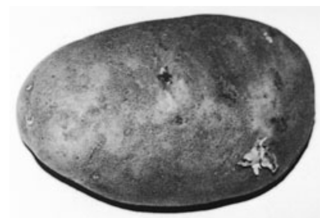
(c) Whole scaly bulb

FIGURE 3–10 A scaly bulb. *(Source: George Acquaah)*



(a) Tuber of *Solanum tuberosum*

(b) Tuber of *Dioscorea* spp.



(c) Whole tuber of potato

FIGURE 3–11 Tubers. These swollen stems vary in size and shape depending on the species. The flesh color is also variable and may be creamish, whitish, yellowish, or some other color. *(Source: George Acquaah)*

7. *Pseudobulbs.* Also called false bulbs, these modified stems are commonly produced by orchids and are variable in appearance. The *Dendrobium* orchid produces an elongated and jointed structure with offshoots at the upper nodes. Once roots form at the base of these offshoots, they may be removed and transplanted. The most popular orchids (e.g., *Cattleya, Miltonia, Laelia*) can be propagated by using rhizomes or stolons divided into sections containing about five pseudobulbs.
8. *Tubers.* In plants such as yam (*Dioscorea* spp.) and white (or Irish) potato *(Solanum tuberosum),* the underground stems are highly enlarged as storage organs (Figure 3–11). Caladium is a popular tuber plant. Whereas Irish potato tubers are generally small in size, yam tubers vary widely in size and shape, according to the species, some attaining lengths of several feet. Tubers have nodes and axillary buds called eyes. Tubers develop best under reduced photoperiod (short days) and lower night temperatures. However, shoot development is vigorous under long-day conditions.
9. *Tuberous roots.* They lack nodes and axillary buds, the buds are present only at the shoot (proximal) end.

3.4 Leaf

There are five types of leaves: *foliage leaves, bud scales, floral bracts, sepals,* and *cotyledons.*

3.4.1 FUNCTIONS

The major functions of leaves are the following:

1. *Food manufacture.* The most widely known function of the leaf is photosynthesis. This function is performed by *foliage leaves,* which are the most readily visible type of leaf.

2. *Protection.* Buds (vegetative or floral) are delicate tissues that need protection while developing. Several nonfoliage leaves assume the important role of protecting developing buds:
   a. *Bud scales.* Also called *cataphylls,* bud scales are modified leaves that protect buds (apical or axillary) while in the resting stage (dormancy) or vegetative buds.
   b. *Floral bracts.* Floral bracts, also called *hypsophylls,* protect the inflorescence during development. They perform a role similar to that of cataphylls.
   c. *Sepals.* Collectively called *calyx,* sepals operate like hypsophylls. Sepals are not durable, however, and often either senesce or abscise after the flower has fully expanded to its mature size. In certain flowers, sepals may be brightly colored like petals and may exude fragrances and produce nectar.
3. *Storage.* Storage as a function of the leaf is often overlooked. *Cotyledons* (or seed leaves) store food that the embryo depends on early in life while the seed germinates until the seedling has developed roots and sometimes leaves to start photosynthesis.

3.4.2 STRUCTURE

Foliage Leaves

Most leaves consist of a flat and thin structure called the *leaf blade,* or *lamina,* that is attached to the stem or branch by a narrow stalk called a *petiole* (Figure 3–12). The lamina may be *simple* or *compound*. Leaves lacking this stalk and attached directly to the stem are said to be *sessile.* The leaf is *dorsoventral* (flattened top to bottom), and as such the epidermis on the *adaxial* (upper) and *abaxial* (lower) surfaces experiences different environmental conditions. The upper epidermal layer of a leaf has a thicker cuticle than the lower layer. In some families, such as Portulacaceae and Begoniaceae, certain species have no *stomata* (openings or pores in the epidermis) on the adaxial epidermis. These pores are bordered by specialized cells called *guard cells* (Figure 3–13). In floating species of families such as Ranuculaceae, abaxial stomata are lacking; in completely submerged plants, such as certain species of Nymphaeaceae, stomata may be absent altogether.

Most stomata occur on the abaxial surface, as do trichomes. The internal part of the leaf, the *mesophyll,* is equivalent to the cortex in the stem (Figure 3–14). Directly below the upper epidermis are columns of cells called *palisade parenchyma.* There may be

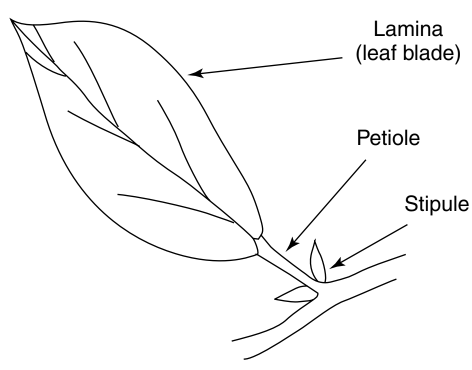


FIGURE 3–12 A typical broad leaf. The size, shape, and other features vary widely among species.

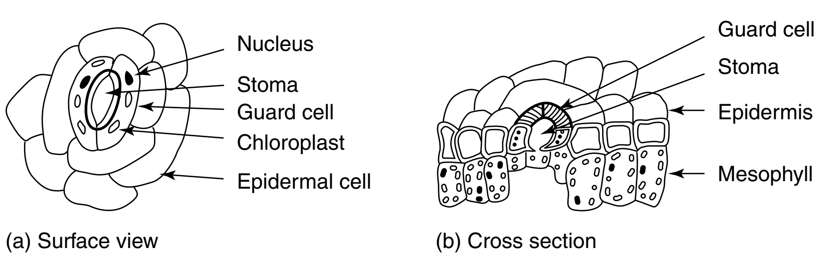


FIGURE 3–13 (a) A surface view and (b) cross section of a stoma.

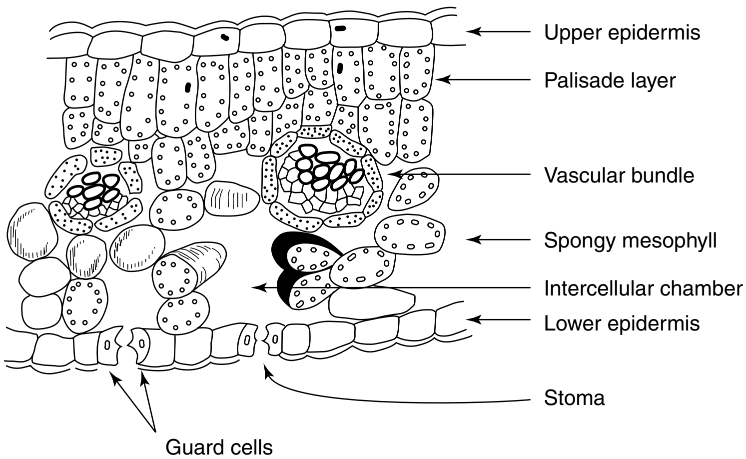


FIGURE 3–14 A transverse section of a typical dicot leaf showing internal structure.

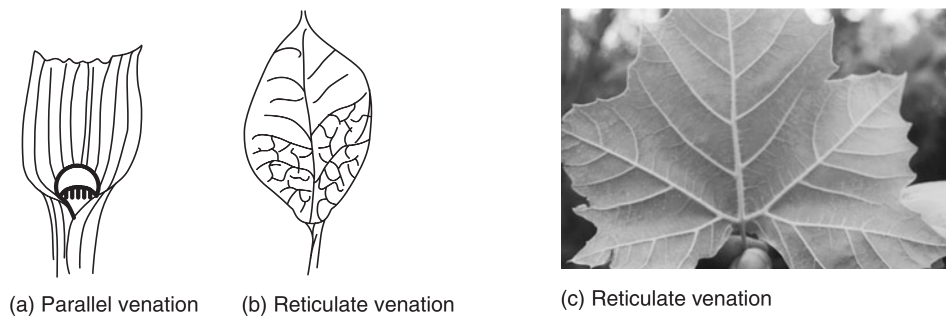


FIGURE 3–15 Leaf venation in a (a) monocot, (b) dicoty, (c) an actual dicot leaf venation. *(Source: George Acquaah)*

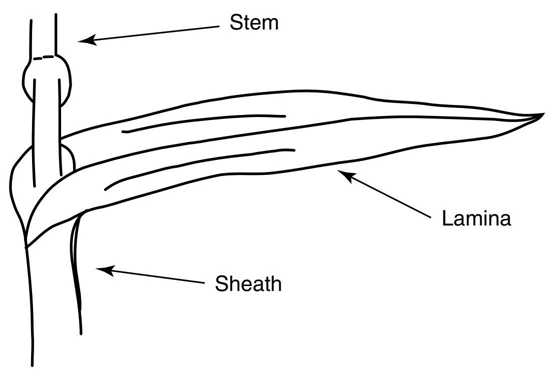


FIGURE 3–16 A typical grass leaf.

more than one row of this tissue if the plant is exposed to intense sunlight. Palisade tissue cells contain chloroplasts used in photosynthesis. Next to the lower epidermis is a layer of widely spaced cells called *spongy mesophyll.* This tissue provides flexibility of the lamina as it moves in the wind.

The vascular system of the stem extends to the leaf. Dicot leaves generally have a single, large *central vein,* or *midrib,* from which secondary and tertiary veins branch out into the lamina. This vascular system provides the framework of the leaf. The pattern of veins (called *venation*) is a basis for classifying plants. Dicots have *reticulate venation* (weblike), while monocots have *parallel venation* (Figure 3–15).

Leaves drop after a period of being on the stem. In dicots, a zone called the *abscision zone,* located at the base of the petiole, is responsible for the dropping of leaves as they age or as a result of adverse environmental conditions. The base of the petiole is a swollen structure called a *pulvinus,* enlarged as a result of water imbibed by the parenchyma cells in that region. Under moisture stress, the pulvinus cells lose water and collapse, resulting in drooping of the petiole. When the pulvinus becomes turgid again, the leaf is lifted up.

Monocot leaves lack a petiole (Figure 3–16). Instead, they have a base *(sheath)* and a lamina with parallel venation. The junction where the lamina attaches to the sheath may have a structure called a *ligule.* An *auricle* or *stipule* may also be present.

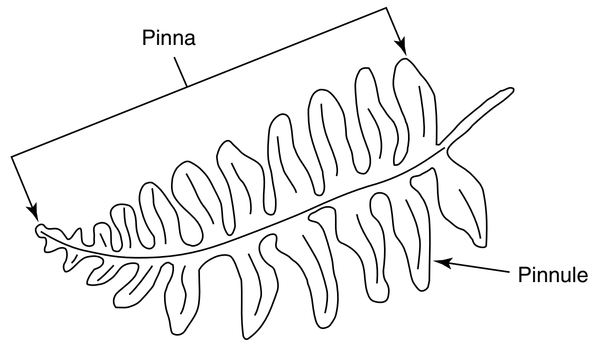


FIGURE 3–17 A fern leaflet (pinna). The fern leaf, called a frond, is typically dissected. The leaf blade is usually segmented into pinnae, which are attached to the main axis (rachis) of the frond. The lower surfaces of the pinnae may be covered with clusters of sporangia enclosed in structures called indusia (singular: *indusium*). These structures give a rust-colored appearance to the pinnae.

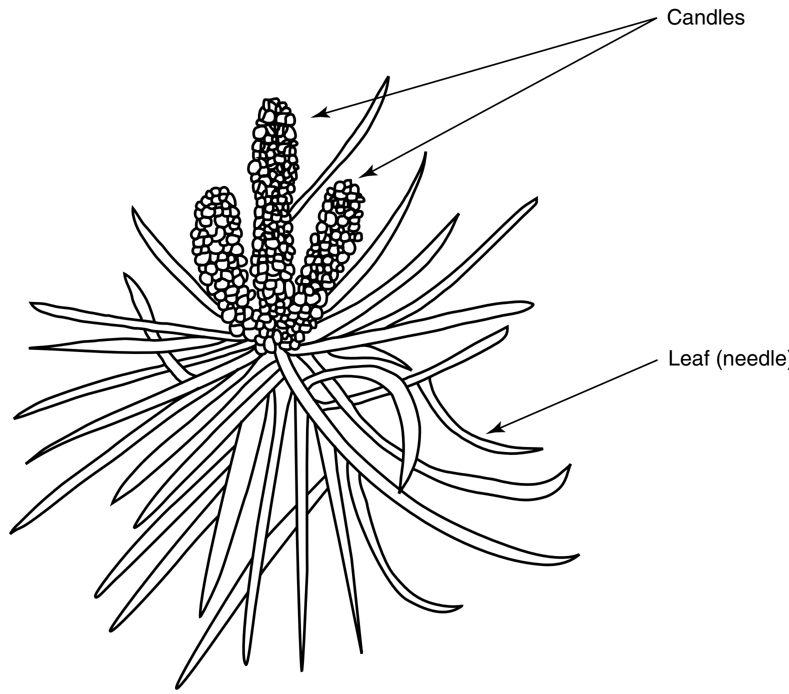


FIGURE 3–18 Pine leaves are also referred to as needles. If a number of leaves are held together, each cluster or fascicle of needles forms a cylindrical rod.

Leaf organization in ferns is similar to that of dicots. However, the lamina is usually compound (Figure 3–17). The venation of mature fern leaves is open and dichotomously branched. Few ferns have reticulate venation. The leaves of conifers are always simple and perennial. They are leathery, tough, and sclerified. The epidermis consists of thick-walled cells. In the pine family (Pinaceae), the leaves are long and needlelike (Figure 3–18). *Transfusion tissue* occurs around the conducting tissue, and resin canals are also characteristic of conifer leaves.

Modified Foliage Leaves

Xerophyte
A plant adapted for growth in arid conditions.

Xeromorphic Foliage Leaves Certain plants have leaf anatomy and growth forms that are adapted to desert conditions. These plants are called **xerophytes** and are characterized by a thick-walled epidermis and hypodermis. The epidermis is covered by a dense and waxy cuticle. A large number of trichomes are found, and many have salt glands. To decrease transpirational loss under xeric conditions, the external surface of xeromorphic leaves is small. The leaves may be small in size, cylindrical, and succulent. The internal packaging of cells is also tight so as to reduce the surface area for moisture loss. The spongy mesophyll may be completely absent in some cases. Water storage cells usually occur in xerophytes. In certain species, leaves are shed after only a few weeks. This strategy reduces the danger of excessive transpiration in the event of a severe drought. Such species, however, are capable of producing a fresh flush of leaves when the rains return.

Submerged Foliage Leaves Aquatic plants have submerged foliage leaves. These plants are called *hydrophytes* (e.g., *Eleocharis, Najas,* and *Sagittaria*). Since they do not need to conserve moisture, their leaves have thin cuticles. Similarly, other cell walls tend to be thin. *Gas chambers* in the spongy mesophyll trap internally generated gases, making the leaves buoyant.

Bud Scales

Bud scales (cataphylls) are leaves designed for protecting buds (apical or axillary). This type of leaf is absent in annual plants in which there are no terminal resting buds. Plants that grow continuously or have only brief resting periods (such as tropical plants) also lack bud scales. However, some types of plants such as mango *(Mangifera indica)* have resting buds protected by bud scales. Bud scales are especially critical in temperate perennial species for protection against desiccation from winter winds and insect damage. The epidermal layer may be composed of cells with thickened walls. More commonly, however, the epidermis forms a protective layer of corky bark. Since there is little need for conduction, vascular tissue may occur in limited amounts. Similarly, stomata are very uncommon and, if present, eventually are lost when cork forms.

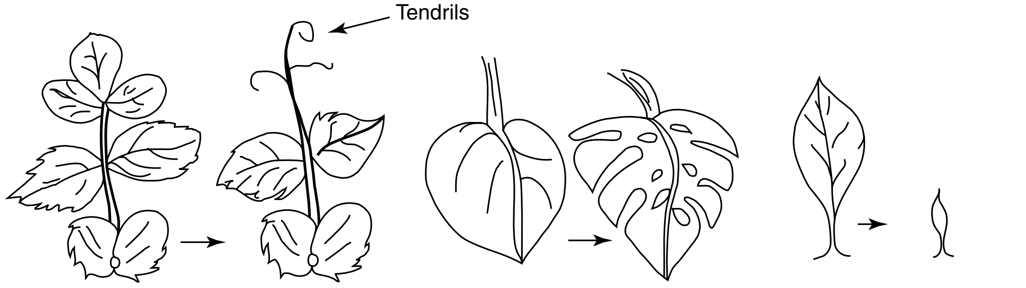
Floral Bracts

Floral bracts (hypsophylls) are leaves designed to protect the inflorescence during development, as previously stated. They are similar to bud scales but are weaker. Usually green in color and thus capable of photosynthesis, they are less resistant than bud scales to environmental factors.

3.4.3 GENERAL LEAF MODIFICATIONS

In some species, modified leaf forms occur along with the normal forms on the same plant. Some of these modifications bear no resemblance to leaves when viewed casually (Figure 3–19). Modified leaves serve a variety of functions:

1. Some are glands for secretion of various substances.
2. The spines or thorns found on some plants protect the plant against pests and animals.
3. Some modified stems (such as bulbs) have leaves that store food.
4. Under arid or xeric conditions, xerophytes develop a thick-walled epidermis and hypodermis. These structures are covered with wax that resists the attack of chewing insects and also protects the leaves from excessive light.
5. Plants that grow under submerged conditions (hydrophytes) have very thin cuticles and cell walls.



(a) Tendrils of *Pisum* (b) Fenestrated leaf of *Monstera* (c) *Berberis* leaf reduced to spine

FIGURE 3–19 Modified leaves. (a) The terminal leaflets of a pea compound leaf may change to become stringy tendrils. (b) When grown under intense light, the solid leaf of *Monstera* develops holes. (c) In certain species, the leaf lamina may be drastically reduced to become a spine.

FIGURE 3–20 Selected common leaf forms: (a) filiform, (b) linear, (c) elliptic, (d) lanceolate, (e) ovate, (f) obvate, (g) hastate, (h) cordate, (i) peltate, (j) spatulate.

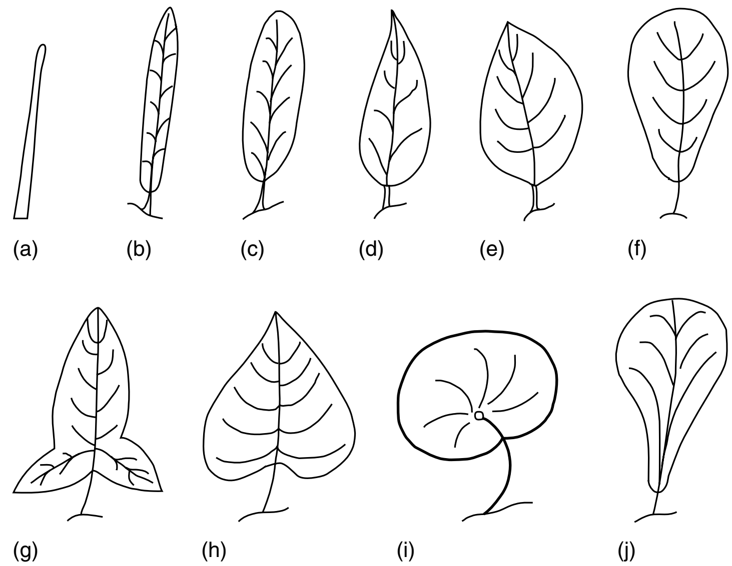
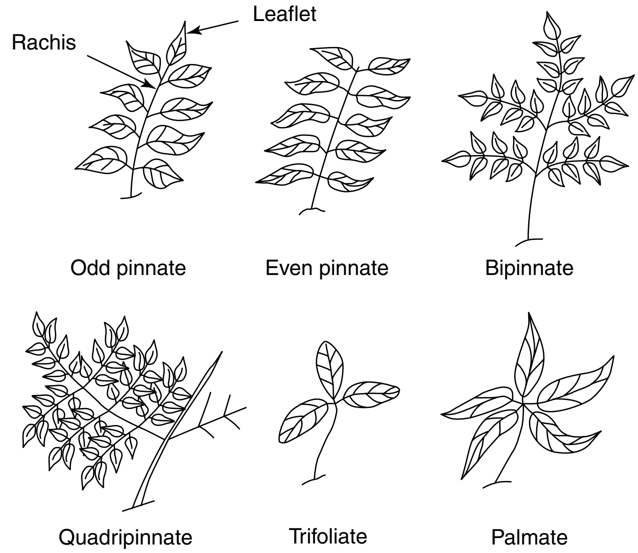


FIGURE 3–21 Selected common leaf shapes.



3.4.4 FOLIAGE LEAF FORMS

The form of a leaf refers to the shape of the lamina. Leaves range from narrow needles (as in pines) to circular shapes as in water lily *(Victoria amazonia)*. The most common leaf forms are shown in Figure 3–20. Each shape is representative of only the particular class, since there are degrees of expression as well as size in each group. Certain leaf forms involve incomplete or partial separation of the lamina into parts called lobes. Certain species have deeply lobed leaves.

3.4.5 COMPOUND LEAF SHAPES

Simple leaves occur individually with one lamina (single leaf). A *compound leaf* consists of two to many small leaves (leaflets or *pinnae*) arranged on either side of the midrib or rachis in a variety of patterns (Figure 3–21). Compound leaves with this arrangement are called *pinnate leaves*. In certain species (e.g., ferns), the pinna is further subdivided into secondary segments, or *pinnules*. Leaves with secondary segments are called *bipinnate leaves*. Further subdivision produces *tri-* and *quadripinnate leaves*.

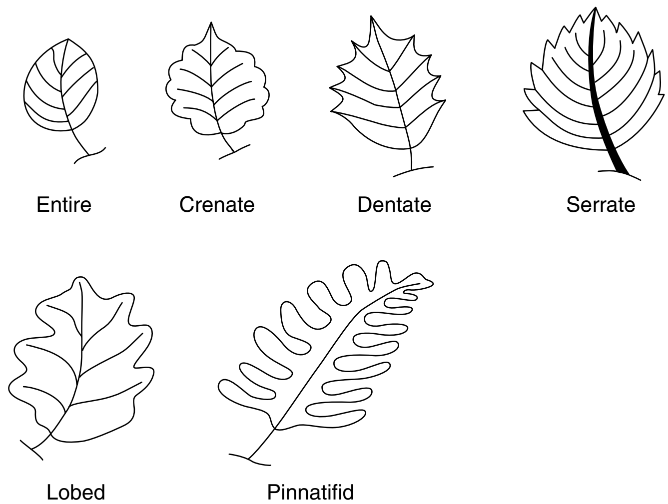


FIGURE 3–22 Selected common leaf margins.

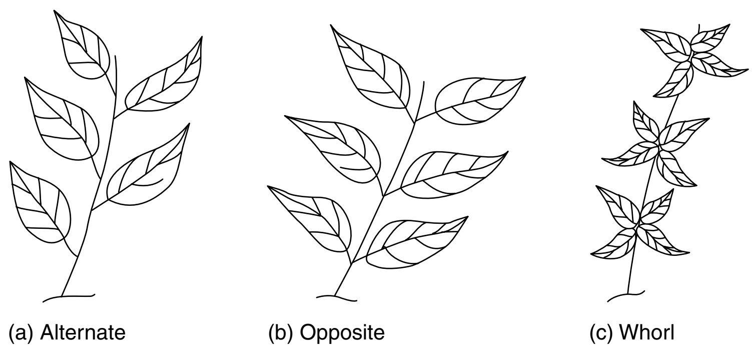


FIGURE 3–23 Selected common leaf arrangements.

3.4.6 LEAF MARGINS

A leaf may have an unindented margin or border or an indented one. In the latter case, there are also degrees of expression, some being more deeply incised than others (Figure 3–22). Some leaf margins or edges are smooth, whereas others are jagged or serrated.

3.4.7 LEAF ARRANGEMENTS

The three basic leaf arrangements are *alternate, opposite,* and *whorl* (Figure 3–23). An alternate arrangement involves leaves set on opposite sides of the branch or stem in a staggered pattern. In opposite arrangement, the placement of leaves is in opposite pairs; in a whorl arrangement, leaves are placed around the stem at each node.

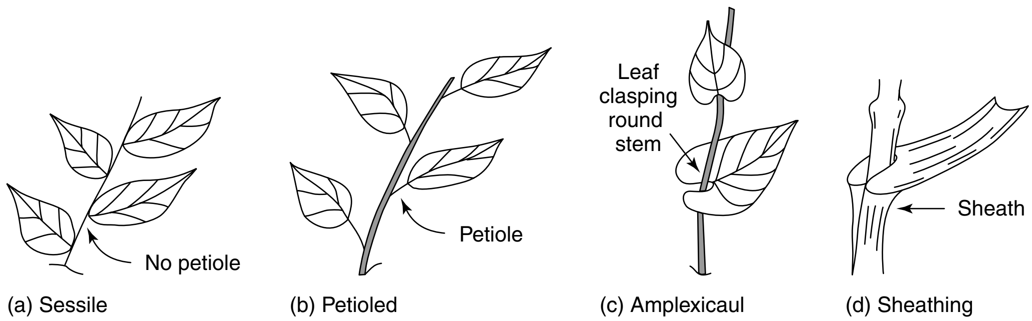
3.4.8 LEAF ATTACHMENT

Figure 3–24 shows a variety of leaf attachments in plants. Grasses have sheathing *(sheath)* attachment to the stem of the plant, as in the case of corn, in which a tubular structure protectively surrounds the stem. Some leaves arise directly from the plant stem and are called *sessile.* Other are attached to the stem by a stalk called a *petiole.*

3.4.9 LEAF TIPS AND BASES

Plants exhibit a wide variety of shapes in the leaf tip and base (Figure 3–25). Tips may be pointed or rounded. In the leaf base, certain species have an indented lamina at the petiole-lamina junction (e.g., *cordate*), and others are straight (e.g., *hastate*).

FIGURE 3–24 Selected common leaf attachments.



3.5 Roots

The root is the underground vegetative organ of a plant.

3.5.1 FUNCTIONS

Roots have several functions, some of which are universal and others that are limited to certain species.

General Functions

1. *Anchorage.* Roots hold up or anchor the stem and other aboveground plant parts to the soil. If not properly anchored in the soil, a plant can be toppled easily by the wind.
2. *Nutrient and water absorption.* Most of the nutrients and water required for plant growth are obtained from the soil. These are absorbed into the plant through its roots.
3. *Hormone synthesis.* Some hormones (cytokinins and gibberelins) required for shoot development and growth are synthesized in the roots.

Specialized Functions

1. *Storage of carbohydrates.* Some species (e.g., sweet potato) have swollen roots that store carbohydrates (Figure 3–26). The plant falls back on such food reserves during times of limited food.
2. *Aerial support.* Even though roots are mostly underground, some species have *aerial roots.* In some grasses, such as corn, modified roots called **prop roots** provide additional anchorage for the plant to its growing medium (Figure 3–27). In climbers, including some ivy, aerial roots enable plants to cling to walls and other structures that they climb (Figure 3–28).

Prop Roots
Adventitious roots that originate from the shoot and pass through the air before entering the soil.

3.5.2 TYPES OF ROOTS AND ROOT SYSTEMS

Roots that develop from a seed are called *seminal roots.* Seminal roots are called the true roots of the plant. A germinated seed produces a young root called a *radicle.* The radicle grows to become the *primary root* of the plant from which *lateral roots* (or *secondary roots*) emerge (Figure 3–29). Any "root" (other than the true root) that originates from other parts of the plant is said to be *adventitious* (e.g., the prop roots in corn or nodal roots or crown roots in other plants). There are two basic root systems.

Tap Root
The radicle is more prominently enlarged than any of the laterals.

1. *Tap root.* The **tap root** system, also called the *primary root* system, is characterized by a large central axis that is larger than the lateral roots that develop from it (Figure 3–30). A tap root grows deep into the soil as the

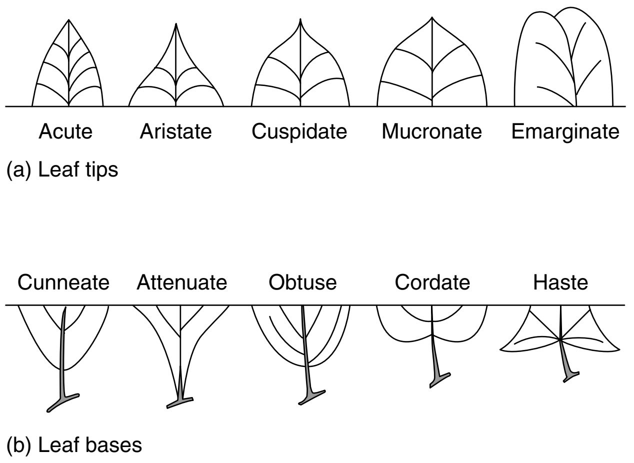


FIGURE 3–25 Selected common leaf tips and bases.

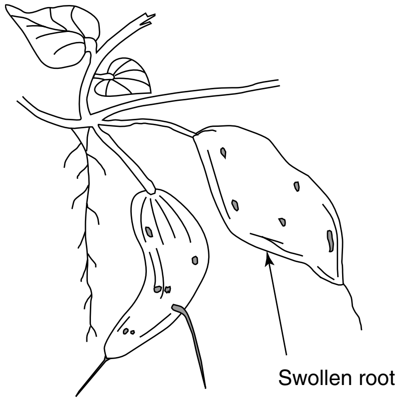


FIGURE 3–26 A swollen root. This root modification may assume a conical and elongated shape, as in carrot *(Daucus carota),* or a round shape, as in radish *(Raphanus sativus).*

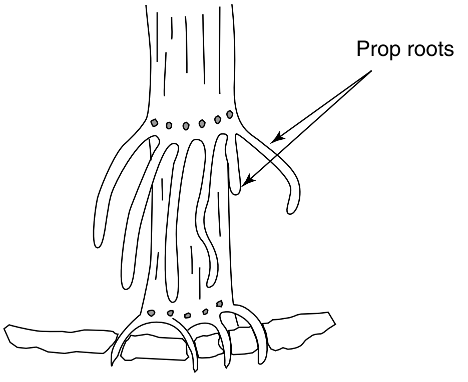


FIGURE 3–27 Prop roots of corn *(Zea mays).*

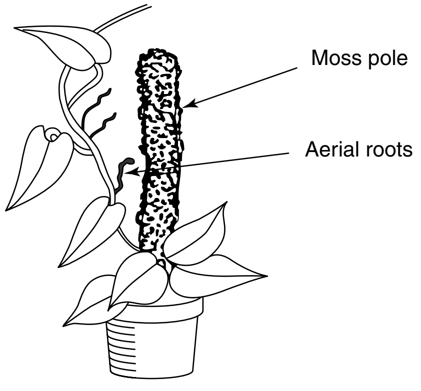


FIGURE 3–28 Aerial roots are used in certain species to aid in the climbing of vines onto nearby physical supports.

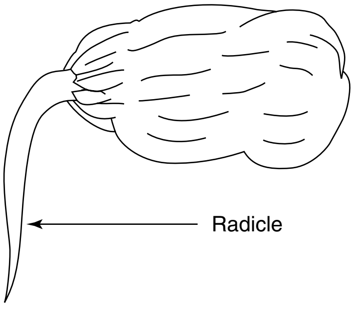


FIGURE 3–29 A radicle of a germinating seed.

FIGURE 3–30 (a) Tap root system. A tap root may be a swollen root, as found in carrot *(Daucus carota)* and radish *(Raphanus sativus)*. (b) Fibrous root system.

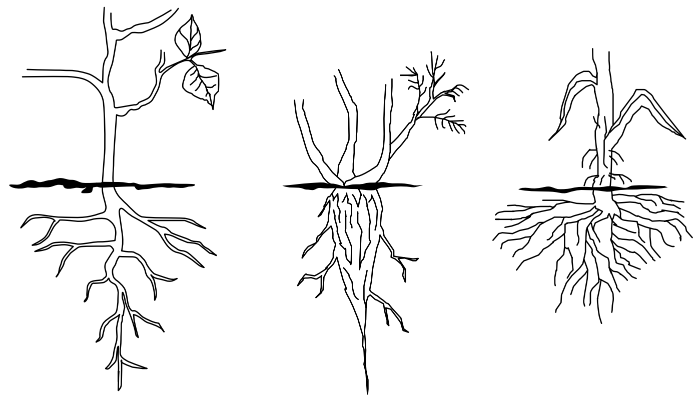


FIGURE 3–31 Transverse sections of dicot and monocot roots.

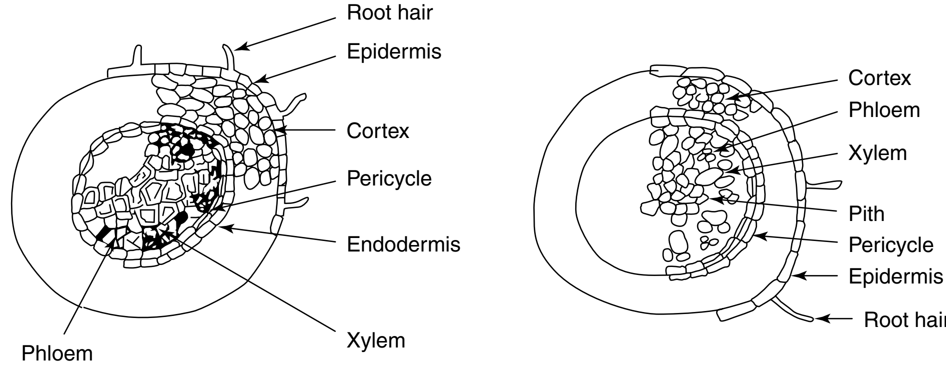
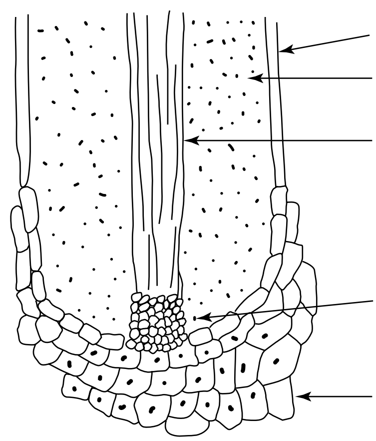


FIGURE 3–32 A longitudinal section of a root cap region.



conditions of the medium permit and provides a strong anchor for the plant. The tap root system is seen in dicots and gymnosperms.

2. *Fibrous root.* The fibrous root system is found in monocots and is characterized by the lack of a single dominant root (Figure 3–30). A dominant root is absent because the radicle of the embryo dies immediately after germination. Instead, a number of lateral roots develop, but they do not penetrate the soil as deeply as the tap root.

The transverse sections of a tap root of a dicot root and monocot root are presented in Figure 3–31. A root exhibits endodermis in the inner layer, which is rare in stems. The conducting vessels in the roots are connected with the vessels in the stem and other plant parts. The tip of the root is protected by the *root cap* (Figure 3–32). As the root pushes its way through the soil, it sheds its peripheral cells. These cells are replaced as they are shed. The root epidermis is usually one cell layer thick. One feature of the root system is the occurrence of *root hairs,* structures often associated with absorption of water and minerals from the soil. The density of these hairs within the soil depends on the environmental conditions. Roots usually produce more hairs under dry conditions and less under moist conditions and are relatively short-lived. When roots grow through a medium of differential nutritional quality and moisture, the parts in more favorable conditions (high moisture, high fertility) assume an accelerated growth period called *compensatory growth,* while the growth of other parts slows down.

3.6 Structure of Wood

All plants consist of what is called a *primary vegetative body.* This body is made up of the three basic organs—stem, leaf, and root. These organs, however, occur in their soft form (i.e., they have no wood). In herbaceous dicots, ferns, and most monocots, this primary vegetative phase persists throughout the lifetime of the plant. However, nonherbaceous dicots and gymnosperms are able to initiate a secondary body within the primary one using *secondary tissues.* The result is a woody plant with a large body. For example, instead of being like an herb, a tree is the result of secondary growth. It is important to note that even in woody plants, primary vegetative tissue may occur in certain parts.

The tissue responsible for part of the secondary growth in woody plants is called the **vascular cambium.** This tissue occurs as a continuous ring of several layers of cells located between the xylem and the phloem tissues. The region where it occurs is called the *cambial region.* In plants such as cactus and euphorbia, the cambial layer is less pronounced and confined to the vascular bundles.

Vascular Cambium
A sheetlike fundamental type of meristem that produces secondary xylem and phloem.

In active plants, the cells in the cambial region divide to produce cells that differentiate into conducting tissues. The secondary growth that occurs to the interior of the vascular cambium produces the secondary xylem, or **wood.** The activity of the vascular cambium is influenced by the environment, specifically by moisture and temperature. Under favorable conditions the cambium is active, but it is dormant under adverse weather conditions such as drought and cold temperature. Once formed, the secondary xylem remains in the stem. As the new layer develops, the older layer is pushed outward in a radial manner. This process makes the plant grow larger and stronger. In situations in which cambial activity is influenced by the environment (especially temperature), a cyclical pattern develops such that **annual rings** representing the previous secondary xylem tissues are observable (Figure 3–33). In such cases, the age of woody plants can be estimated from the number of such rings found in the wood. However, in species such as ebony *(Diospyros ebenum)* that grow in benign or seasonless tropical regions, annual rings are not formed. On the other hand, plants that grow under conditions of erratic moisture, such as that in arid and semiarid regions, may produce more than one growth ring per year in response to moisture patterns. The science of studying growth rings is called *dendrochronology.*

Wood
Secondary xylem.

Annual Rings
Cylinders of secondary xylem added to the stem of a woody plant in successive years.

Wood may be classified according to the kind of plant that produces it. Nonflowering plants found in temperate regions (e.g., spruce, pine, fir, and larch) produce wood

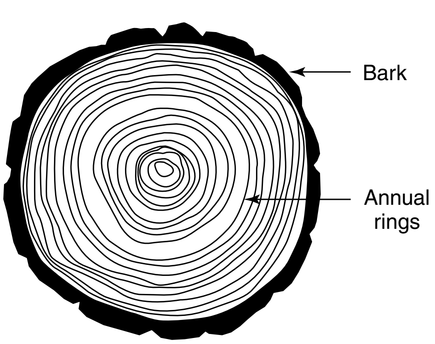


FIGURE 3–33 Annual rings of a woody dicot stem. A ring is equivalent to one year's growth of the xylem tissue.

FIGURE 3–34 Heartwood and sapwood. Heartwood consists of nonconducting tissue; sapwood is still-functioning xylem tissue.

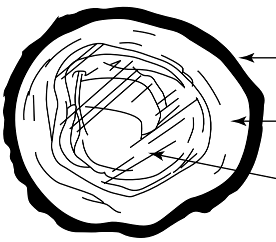


FIGURE 3–35 Tension wood. This reaction wood of dicots is found on the upper side of the branch and consists of large amounts of gelatinous fibers.

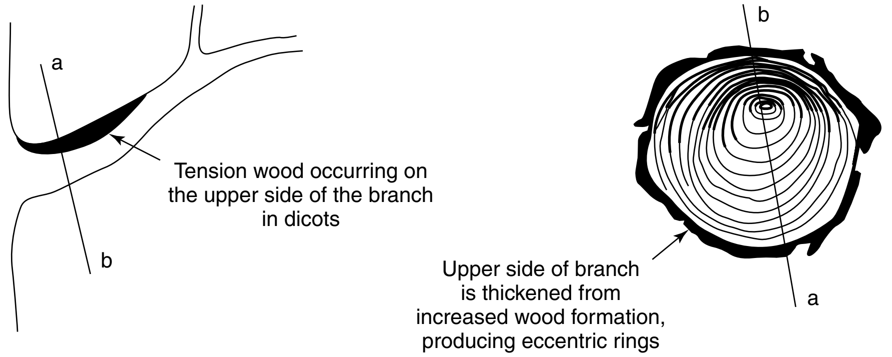
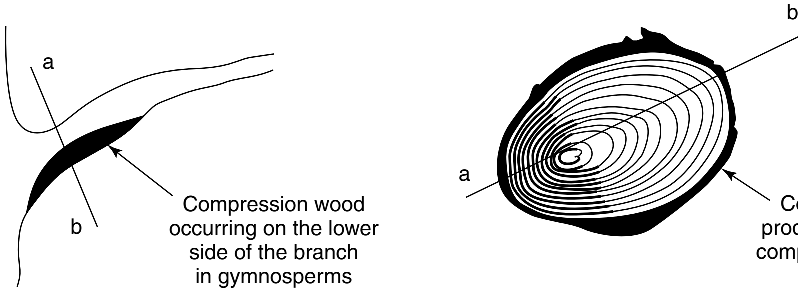


FIGURE 3–36 Compression wood. In conifers the reaction wood forms on the lower side of the branch. This wood is heavier and more brittle than normal wood.



Softwood
Wood produced by a conifer.

that is relatively homogeneous. This wood, called **softwood,** is composed predominantly of tracheids without vessels. Because softwoods are readily penetrable by nails, they are widely used in construction. They contain large amounts of lignin, which makes them desirable for use as lumber, because lignin stabilizes the wood and reduces warping.

The wood of dicots found in temperate and tropical zones is composed predominantly of fibers and vessels. These structures make the wood stronger and denser, the resultant wood being called *hardwood.* Examples of hardwood include walnut, oak, maple, ash, and hickory. These woods are characteristically hard to nail and hence not preferred for construction.

Wood may also be classified on the basis of location and function. Conduction of sap occurs only in outer secondary xylem where the wood is relatively weak. This part of the wood is called *sapwood* and is light and pale colored (Figure 3–34). The center of the wood is dry, dark colored, and dense as a result of the deposits of metabolites such as gums, tannins, and resins. This wood is called *heartwood.* Sapwood converts into heartwood as the plant grows older.

Reaction Wood
Wood produced in response to a stem that has lost its vertical position.

Branches of trees are attached to the trunk at a variety of angles. They sway in the wind and are weighed down by gravity. These external factors cause the plant to respond by developing a special kind of wood called **reaction wood.** In dicots, this specialized wood is called *tension wood* and occurs on the upper side of the stem (Figure 3–35). This wood contains gelatinous fibers made from cellulose, making the wood brittle and difficult to cut. Reaction wood in conifers is called *compression wood* and occurs on the lower side of the branch (Figure 3–36). The amount of wood in the compressed area increases with time and contains a large amount of lignin.

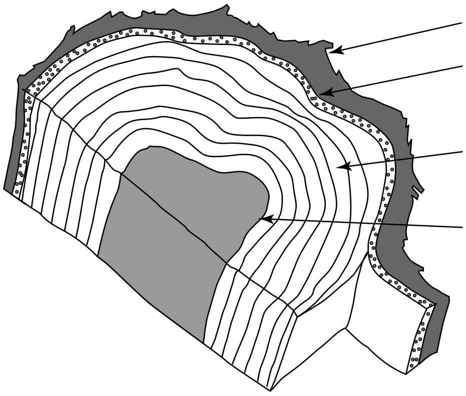


FIGURE 3–37 Tree bark, which is comprised of the tissues outside the cambium, including the phloem.

(a)

(b)

(c)

FIGURE 3–38 Tree bark differs in thickness and roughness. Some are thin and flaky, whereas others are thick and firm. *(Source: George Acquaah)*

3.7 Bark

As previously stated, the secondary xylem produces wood. The secondary phloem is a major part of the **bark** of a tree (Figure 3–37). The bark develops in perennial plants as the epidermis is replaced by a structure called the *periderm.* The periderm is composed of a mixture of cells, some of which are meristematic and are called the *phellogen,* or *cork cambium.* The bark includes the cork cambium and the secondary phloem tissue.

Bark
The part of the stem or root exterior to the vascular cambium.

Bark thickness is variable (Figure 3–38). Some plants, such as *Betula platyphylla,* have very thin bark that peels off easily. Others, such as the cork oak *(Quercus suber),* may have several centimeters (3 centimeters, or 1.2 inches, or more thick) of bark. The texture of the bark varies widely. Some barks are made of short fibers that are not elastic, so as the bark grows and stretches, it cracks deeply, as in the willow tree, and breaks into large chunks. Where the fibers are long, as in the case of junipers, the bark peels off in long pieces. Some barks, such as those found in the madrone *(Arbutus xalapensis),* are flaky. Barks are rare in monocots (e.g., *Aloe dichotoma*). The function of the bark is to protect the plant against hazards in the plant's environment. However, a thick bark that is waterproof prevents gaseous exchange between the plant and environment. Therefore, woody plants have openings in their bark called *lenticels* that allow exchange of gases.

3.8 Flowers

The *flower* is the part of the plant most readily associated with the field of horticulture. It contains the reproductive organs of flowering plants (angiosperms). A typical flower has four parts: *sepal, petal, stamen,* and *pistil.* A developing flower bud is protected by leaflike structures called *sepals*, which are collectively called *calyx.* The most showy parts of the flower are the petals, which collectively are called a *corolla* (Figure 3–39). Petals have color and fragrance that attract pollinators to the flower. The texture of petals may be smooth, or the epidermis may have trichomes (hairs). Usually, petals drop soon after the flower has been pollinated.

The petals in some flowers are about the same size and shape, such as those found in magnolia. These flowers are said to be *actinomorphic* (Figure 3–40). In families that have different types of petals on one flower (such as occurs in clover) the plants are said to be *zygomorphic.* Sometimes the corolla is made up of individual petals, and the flower is described as *apopetalous.* Some flowers (e.g., honeysuckle) have a fused corolla *(sympetalous),* forming a *corolla tube.*

The collective term for the male reproductive organ parts is *androecium.* The stamen is comprised of a stalk called the *filament* that is capped by a structure called an

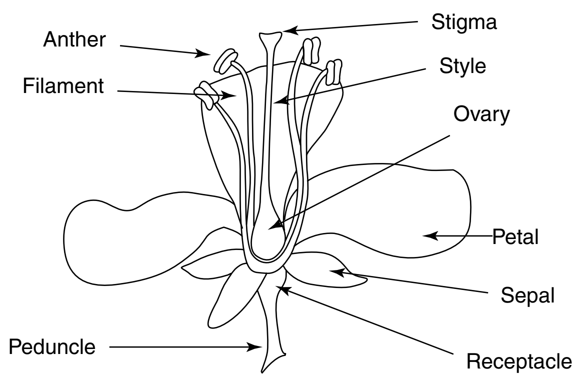


FIGURE 3–39 Parts of a typical flower.

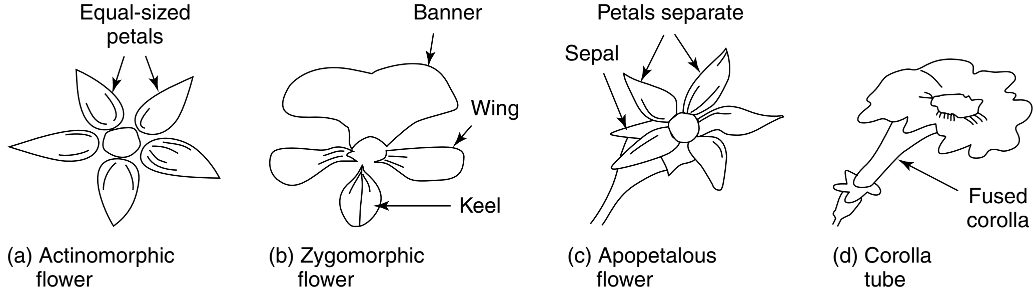


FIGURE 3–40 Selected flower shapes.

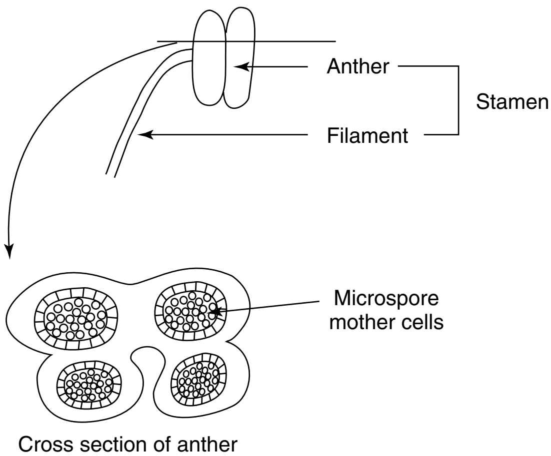


FIGURE 3–41 Whole and cross-sectional view of male flower parts.

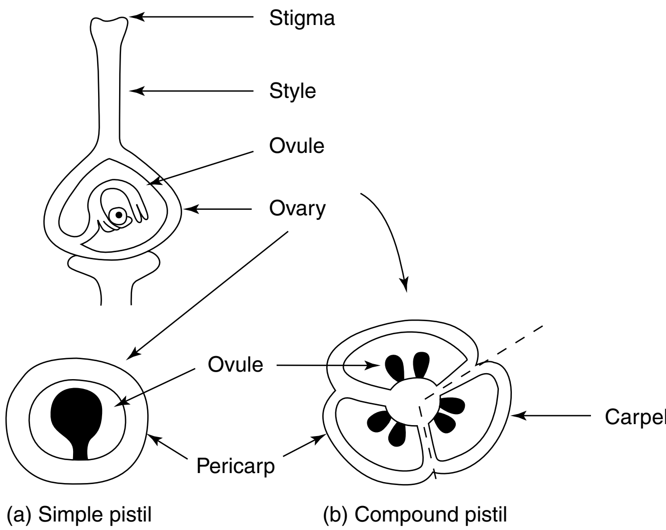


FIGURE 3–42 Whole and cross-sectional view of female flower parts.

anther, the sack that contains the pollen grains (Figure 3–41). The female reproductive parts are collectively called *gynoecium.* The *carpel* consists of three structures: the *style,* which is similar to the filament; is tubular and capped by the *stigma,* a receptacle for receiving pollen grains; and the third structure is the *ovary,* which contains ovules (Figure 3–42). Gymnosperms have no flowers. Instead, their reproductive structures are called *strobili* (singular: *strobilus*).

If a flower has both male and female parts it is said to be *perfect.* When all of the four parts of a flower are present, a *complete flower* exists. If one or more parts are missing, the flower is said to be *incomplete.* Certain flowers are either male or female and, therefore, *imperfect.* In plants described as *monoecious,* both male and female flowers occur in one plant but are physically located on different parts. In sweet corn, the male flowers *(tassel)* occur at the terminal parts while the female flowers *(silk)* occur on the middle region on the leaf axil. Cucumber, walnut, and pecan are also monoecious, and as such both sexes are required for fruiting to occur in cultivation. In *dioecious* plants, such as date palm, holly, and asparagus, however, one plant is exclusively either male or female.

Flowers may occur individually *(solitary)* or in a bunch or cluster (*inflorescence,* as in urn plant, lupine, and snapdragon). The main stalk of an inflorescence is called a *peduncle;* the smaller stalks are called *pedicels.* There are three basic types of inflorescence: *head* (e.g., daisy and sunflower), *spike* (e.g., gladiolus and wheat), and *umbel* (e.g., onion and carrot). These and other types of flower clusters are shown in Figure 3–43.

The physical structure and display of certain flowers make them capable of *self-pollination* (pollen grains from the anther are deposited on the stigma of the same flower). Since the mating system excludes foreign pollen, the species tends to be genetically pure,

FIGURE 3–43 Inflorescence type.

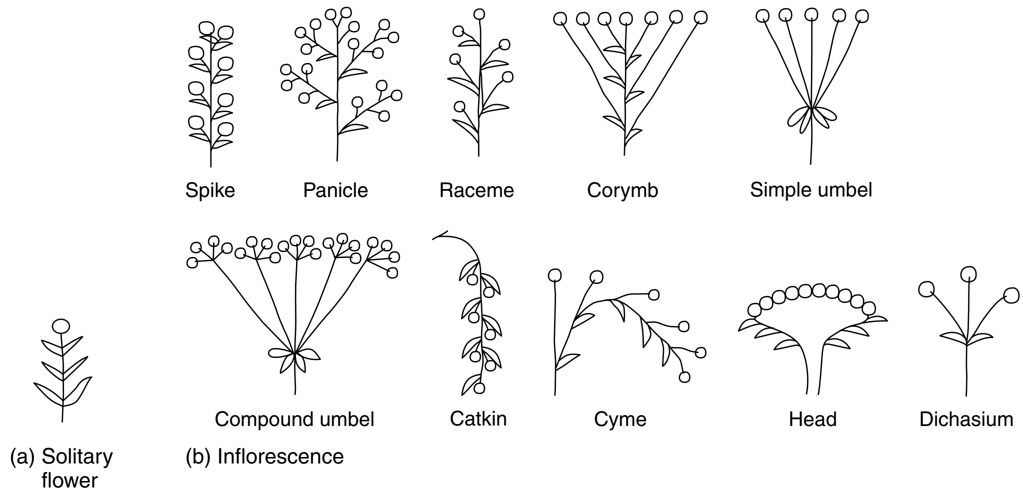


FIGURE 3–44 A dicot seed.

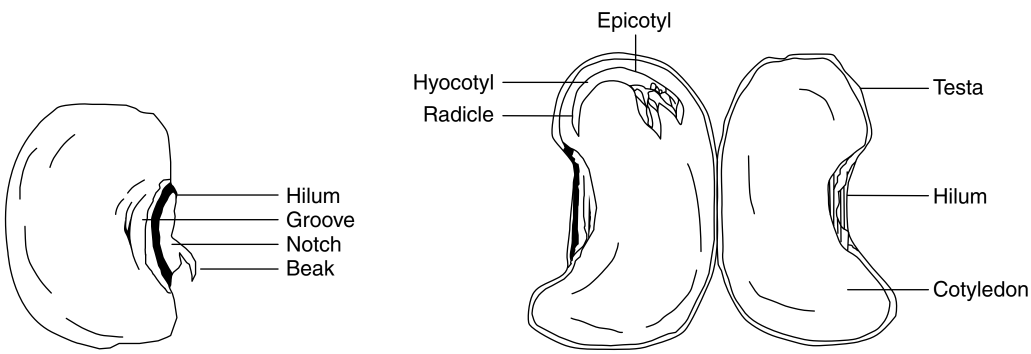
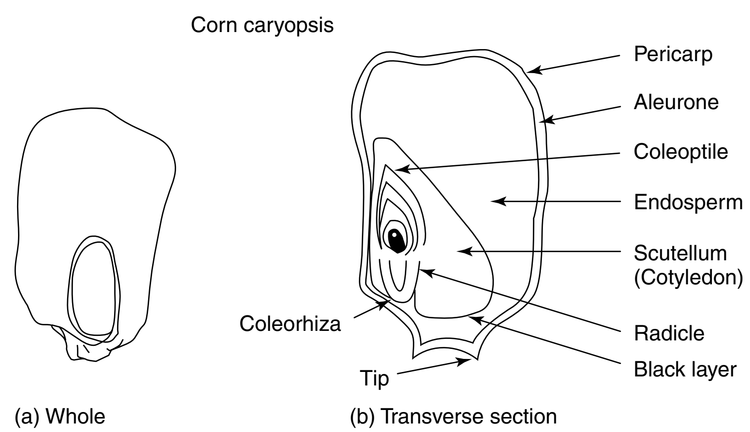


FIGURE 3–45 A monocot caryopsis.



or homozygous. Imperfect flowers have no choice but to engage in *cross-pollination* (pollen transferred from one flower and deposited on a different flower). Insects, birds, mammals, and wind are all agents of this process that promotes heterozygosity by permitting foreign pollen to be deposited.

3.9 Seed

Monocot
A type of angiosperm characterized by seeds with only one seed leaf or cotyledon.

Horticultural plants may be seed bearing (gymnosperms and angiosperms) or nonseed bearing *(cryptogams)*. Seeds remain dormant until the proper environmental conditions for germination prevail. A seed contains an *embryo,* or miniature plant (sporophyte), that is encased in a seed coat, or *testa,* in dicots and a pericarp in **monocots.** In dicots, the embryo is sandwiched between two structures called cotyledons, which function as storage organs (Figure 3–44). Monocots have one cotyledon, which is called a *scutellum* in

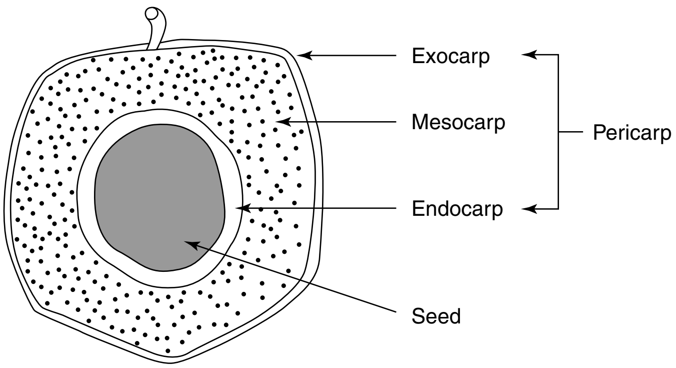


FIGURE 3–46 Parts of a typical fruit.

grasses (Figure 3–45). In grasses, the *endosperm* is the storage organ. The cotyledons provide nutrients for the growing embryo until the seedling is able to photosynthesize.

The **dicot** seed has a tiny opening called a *hilum,* through which water and air enter to initiate germination. In dicots, the cotyledons are pushed above the soil during germination *(epigeous germination),* whereas in monocots, the cotyledon remains underground *(hypogeous germination).*

Dicot
A type of angiosperm characterized by seeds with two seed leaves or cotyledons.

3.10 Fruits

Parthenocarpy
Development of fruit without sexual fertilization.

The mature ovary, together with the associated parts, form the *fruit.* In most species, the fruit bears *seeds*. In others, the fruit may develop without fertilization, a phenomenon called **parthenocarpy**. Parthenocarpic fruits (e.g., Cavendish banana, Washington navel orange, and many fig cultivars) are seedless. The natural function of the fruit is to protect the seed; however, animals and humans most desire the fruit.

A typical fruit has three regions: the *exocarp* (the outer covering or skin), the *endocarp* (a boundary around the seed and may be hard and stony or papery), and the *mesocarp* (the often fleshy tissue that occurs between the exocarp and the endocarp) (Figure 3–46).

The anatomy of fruits is discussed in great detail in Chapter 2, where such description was necessary to help in the classification of fruits.

Summary

Plant anatomy is the science of cataloging, describing, and understanding the functions of plant structures. Eukaryotes have various levels of structural organization. The cell is the fundamental unit of organization of living things. It is totipotent, grows, and ages. Cells consist of a variety of organelles such as mitochondria, chloroplasts, and nuclei, each with specific functions. The mitochondria are involved in energy-related functions, and the chloroplasts in photosynthesis, or food manufacture. The nucleus houses the chromosomes that contain most of the genetic material of the plant.

Plant cells undergo differentiation to produce a variety of types, namely, parenchyma, collenchyma, and sclerenchyma. These types differ in cell wall characteristics and have specific structural roles. Cells aggregate to form tissues with specific functions. Parenchyma cells are thin walled and occur in tissues that have secretory, photosynthetic, and growth functions. Collenchyma and sclerenchyma are thicker walled and have mechanical roles in plant-strengthening tissues. Apart from simple tissues, cells aggregate to form complex tissues such as the epidermis (protective role) and those with secretory functions as found in nectaries. Some complex tissues are involved in the movement of organic and inorganic solutes through the plant. The xylem tissues move water and minerals from the roots to the leaves, where they are used in photosynthesis. The photosynthates are transported from leaves to other parts of the plant through the

phloem tissue. Unlike animals, in which all parts of the organism grow simultaneously, growth in plants is limited to regions called meristems that occur in the apex or axils of the plant.

The primary vegetative body of a plant consists of three organs—root, stem, and leaf. The root is the underground organ involved in anchorage of the plant and absorption of nutrients from the soil. In some species, the roots act as storage organs for carbohydrates. The tap root system, with one large central axis with laterals, is found in dicots, and the fibrous root system, characterized by several dominant roots, is seen in monocots. Tap roots penetrate the soil more deeply than fibrous roots. The stem is the central axis of the shoot of a plant. It holds up the foliage; conducts water, minerals, and food; and sometimes acts as a storage organ. It may be modified to be a vine or may creep (as in stolon), grow horizontally (as in rhizome), or store food (as in bulb, tuber, and corm). The leaf is the primary photosynthetic apparatus of the plant and is usually green in color. It may also be modified to be a storage organ. It varies in shape, size, form, margin, and arrangement.

In dicots, secondary growth in nonherbaceous species produces wood, or secondary xylem. The inner layers of the wood that have lost conducting ability constitute the heartwood, and the outer layer forms the sapwood. Gymnosperms produce softwood because they lack certain strengthening fibers. The secondary phloem produces a tough outer layer called bark that replaces the epidermis. The bark in oak species may be several centimeters thick.

The flower, showy and colorful, is the reproductive organ of the flowering plant. The male organ comprises the filament and the anther (contains pollen grains). The female organ, the carpel, consists of a style that is capped by a stigma and an ovary that contains ovules. After fertilization, a seed is produced. It contains an embryo, or a miniature plant. In dicot seeds, the embryo is sandwiched between two storage organs called cotyledons. Only one cotyledon occurs in monocots. When dicot seeds are planted, they germinate by pushing the cotyledons above the soil surface (epigeous germination). Monocots leave one cotyledon below the ground (hypogeous germination).

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Excellent and well-illustrated presentation of plant anatomy
http://dallas.tamu.edu/weeds/anat.html

Excellent microscope slides of cross sections of plant parts
http://www.unlv.edu/Colleges/Sciences/Biology/Schulte/Anatomy/Anatomy.html

Simple and well-illustrated description of plant structure
http://www.emc.maricopa.edu/faculty/farabee/biobk/BioBookPLANTANAT.html

Practical Experience

Laboratory

1. Obtain prepared slides of transverse sections of dicot stems and roots. Compare and contrast the two kinds of stems and the two kinds of roots.
2. Obtain samples of modified roots:
   - **a.** rhizome
   - **b.** corm
   - **c.** stolon
   - **d.** bulb
3. Obtain samples of leaves from different species showing a variety of forms, arrangement, and margin types.

Greenhouse

Plant a legume seed and a grass seed. Compare and contrast germination or emergence types, the root systems, leaf characteristics, and other anatomical differences.

Field Trip

1. Take a walk across your campus and observe the variety of types of tree bark.
2. Visit a botanical garden or a greenhouse to observe the following:
   - **a.** flower types
   - **b.** leaf types—arrangement, form, and margins

Outcomes Assessment

1. How can an understanding of plant anatomy help one to become a better horticulturalist?
2. Distinguish, giving examples, between a bulb and a corm.
3. Distinguish, giving examples, between a tunicate bulb and a scaly bulb.
4. Discuss the importance of modified stems and roots in the horicultural industry.
5. Discuss the diversity in leaf margins in plants.
6. Describe how wood is formed. What are annual rings?
7. Besides ornamental value, in what ways are flowers important in horticulture?
8. Compare and contrast monocot and dicot seeds.
9. What are adventitious roots? How important are they to plants?