E-UNIT A2–1

# Leaf Structure and Functions

Imagine that you were given an assignment to design a solar collector that would convert sunlight to chemical energy. Where would you begin? Many architects and engineers seek inspiration from nature's designs. If you followed their example, you might want to begin by studying a leaf.

## Objective:

Describe leaf structure and functions.

## Key Terms:

| | | |
|---|---|---|
| abscission | cuticle | spongy mesophyll layer |
| abscission layer | desiccation | stoma |
| bract | guard cell | trichome |
| bulliform cell | leaf | |
| bundle sheath | palisade layer | |

# Leaves

A **leaf** is a plant organ that collects solar energy and converts it to food. Its primary purpose is to conduct photosynthesis; therefore, it is structured in a way to maximize efficiency. Three requirements are associated with leaves as photosynthetic organs.

- Leaves must take full advantage of the available light.
- The mesophyll cells must be continually supplied with enough carbon dioxide ($CO_2$) to maximize photosynthetic activity.

- All leaf cells must have direct cell-to-cell contact with the vascular tissues to receive water and dissolved minerals and to export manufactured sugars.

## FUNCTIONS OF LEAF TISSUES AND CELLS

Leaves of angiosperms (flowering plants) are flattened to make the most of light absorption and the exchange of gases. Exposure to sunlight is also optimized with the way leaves are arranged on a stem. Many angiosperm plants lose all their leaves annually and are said to be deciduous.

Dicotyledon and monocotyledon plants are two classes of angiosperms with distinctly different leaf shapes. A dicot leaf has a broad, flattened blade connected to the stem by a petiole, which is a stem-like structure. There is always a bud at the base of the petiole. A dicot displays netted venation. The blade is flattened to provide maximum exposure of the leaf surface to light. The blades of some plant species are thick and succulent, while those of other species are paper thin. Beans and maples are examples of dicots. In contrast, monocots have long, narrow leaves that lack petioles and are typified by veins running parallel to one another. A monocot leaf wraps around the stem in a sheath. Monocots include corn, grasses, and lilies.

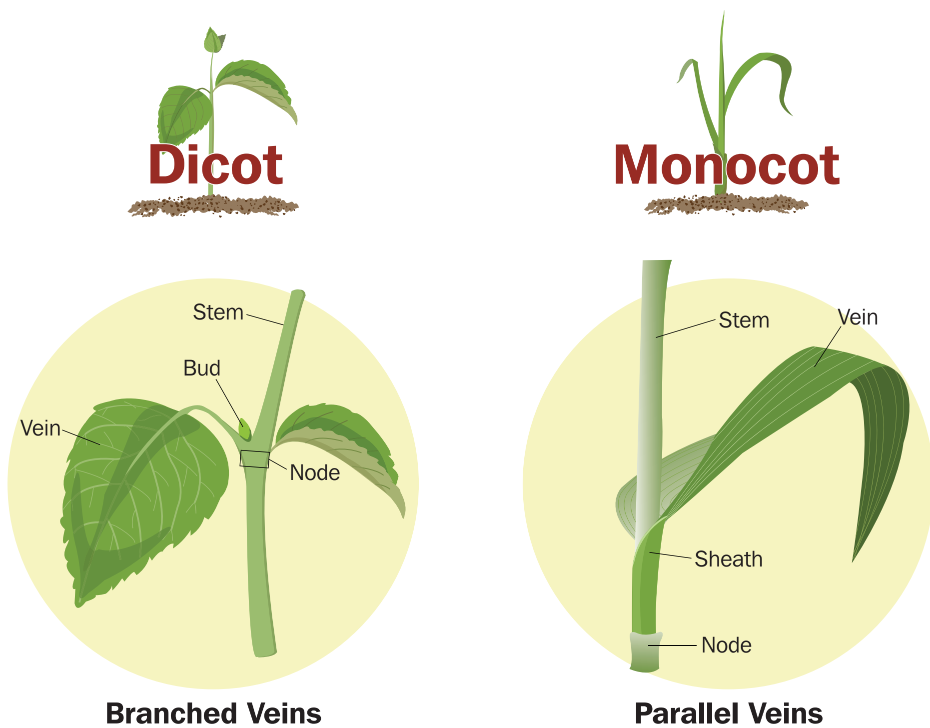


**FIGURE 1. Dicotyledon and monocotyledon plants have distinctly different leaf shapes.**

The lower levels of a tropical rain forest receive little sunlight. As an adaptation, many plants growing on or near the forest floor have leaves that grow very large. The large leaves provide more surface area for capturing what light is available. In a temperate region, large leaves could be a problem in terms of water loss. However, in a rainforest, water is abundant, so there is little stress.

The desert has an abundance of sunlight and limited moisture. Consequently, desert plant adaptations include small leaves or no leaves. Small leaves are sufficient to capture enough sunlight for photosynthesis. The small leaf size also reduces the loss of water from the plants.

Major tissues that make up a leaf are epidermal, mesophyll, and vascular (xylem and phloem).

## Epidermal Tissue

The flattened leaf has two epidermal layers, the upper epidermis and the lower epidermis. The epidermis consists of parenchyma cells that lack chloroplasts and are fairly transparent to allow the transmission of light. Interestingly, the outer cell wall of an epidermal cell is somewhat thicker than the inner cell wall, probably to provide added protection from injury and infection. The epidermal cells secrete a waxy substance called **cuticle** that covers the outer epidermal surface and functions to reduce water loss through evaporation and to prevent external water and solutes from entering the leaf. It is estimated that only 1 to 3 percent of water is lost through the cuticle.

FIGURE 2. The cuticle reduces water loss through evaporation and prevents external water and solutes from entering the leaf.

Specialized epidermal cells called trichomes can be found on the leaves of some plant species. A **trichome** is a long, narrow epidermal cell that grows perpendicular to the surface. Trichomes are either unicellular or multicellular and appear as hairs on the leaves of some plants, such as soybeans. They reduce water loss by slowing air movement close to the leaves and, in the case of desert plants, may protect the leaves from high light intensity. In addition, trichomes discourage some pests from devouring the leaves. Root hairs are another type of trichome.

FIGURE 3. Trichomes can be seen on this soybean leaf.

The leaf epidermis is dotted with numerous stomata (singular: *stoma*). A **stoma** is a tiny pore in the epidermis that regulates the exchange of gases. Stomata are more prevalent on the lower epidermis than on the upper epidermis.

Each stoma is enclosed by two specialized epidermal cells called guard cells. A **guard cell** is one of a pair of cells that regulate the opening and closing of the stoma, through which the diffusion of carbon dioxide, oxygen, and water vapor is allowed. Carbon dioxide diffuses into the open spaces around the mesophyll cells and is taken up by the cells for photosynthesis. Conversely, oxygen produced during photosynthesis exits the leaves through the stomata. Water vapor diffuses out similarly. In fact, the greatest loss of water from a plant is through the stomata. Guard cells are unique epidermal cells in that they contain chloroplasts.

While the guard cells of dicots take on the appearance of tiny kidney beans, those of some monocots look like dumbbells. Monocot guard cells are associated with specialized epidermal cells called subsidiary cells. Subsidiary cells support the function of the guard cells. They lack chloroplasts.

Another difference between dicot and monocot epidermal cells is that many monocots have bulliform cells. A **bulliform cell** is a large, bubble-shaped epidermal cell found in groups on the upper surface of a monocot leaf near the midvein. Bulliform cells are large, empty, and colorless. Their function is to minimize water loss during stress conditions. When water is plentiful, bulliform cells become turgid from the absorption of water. Their turgidity causes the leaf to straighten up. As a result, some loss of the water is permitted. When the water supply is short, bulliform cells become flaccid, causing the leaf to curl inward, thus reducing exposure and minimizing water loss. This curling of leaves is a characteristic of corn plants under water stress.

## Mesophyll Tissue

Between the epidermal layers is the primary photosynthetic tissue called the mesophyll. The mesophyll consists of parenchyma cells organized into two regions. One region, the **palisade layer**, is a tight stratum of vertically arranged mesophyll cells lying just below the upper epidermis. Cells of the palisade layer contain three to five times as many chloroplasts as those of the other region, the spongy mesophyll layer. The **spongy mesophyll layer** is a loosely arranged layer of cells beneath the palisade layer that is interspersed with an open intercellular system. The cavities between the spongy mesophyll cells are in direct contact with the atmosphere via the stomata.

Mesophyll cells contain different colored pigments, including chlorophyll, carotenoids, and anthocyanins.

Chlorophyll is the primary pigment involved in photosynthesis and is the most efficient light-capturing pigment. Leaves appear green because chlorophyll is the most abundant pigment in the leaves of a growing plant. Chlorophyll is found in two forms. “Chlorophyll a” is a bright green pigment responsible for absorbing energy from the violet-blue to red, red-orange light wavelengths. “Chlorophyll b” is a yellow-green pigment that absorbs red-blue wavelengths of light.

**Cell Structure of a Leaf**

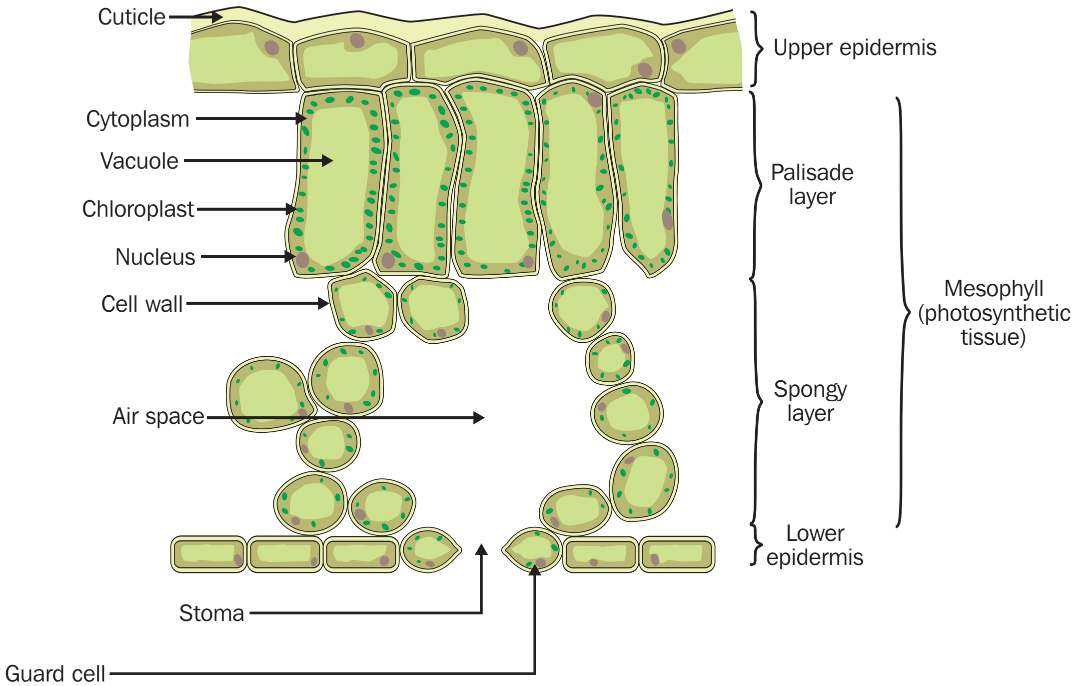


**FIGURE 4. The primary photosynthetic tissue, called the mesophyll, consists of parenchyma cells organized into two regions.**

Carotenoids are supplementary pigments divided into two groups, carotenes and xanthophylls. In general, carotenoids absorb energy from green-violet wavelengths. The energy absorbed by carotenoids can be transferred to "chlorophyll a." Although carotenoids are yellow, orange, and red in color, they are usually hidden by the chlorophyll pigments. Another function of carotenes is to help protect plants from excessive light intensity.

Anthocyanins belong to a class of molecules called flavonoids and appear red, purple, or blue depending on the pH. In leaves, these pigments are generally produced toward the end of summer. Anthocyanins give flowers and fruit the colors that attract animals. They protect plants from overexposure to ultraviolet light and extreme temperatures.

## Vascular Tissue

Throughout the mesophyll is a network of veins consisting of xylem and phloem tissues. The xylem, which delivers water and dissolved minerals to the leaf tissues, is located on the upper side of the vein. The phloem, which carries sugars from the leaf, is located on the bottom side of the vein. Veins are numerous enough so every cell is reached for exchange of materials.

Veins are encircled by a bundle sheath. The **bundle sheath** is one or more layers of parenchyma or sclerenchyma cells wrapped around vascular tissue with the functions of regulating the movement of substances between the vascular tissue and the mesophyll and protecting the vascular tissue from exposure to air. In $C_4$ plants, the bundle sheath cells contain chloroplasts and are the site of the Calvin cycle.

## GYMNOSPERM LEAVES

Gymnosperm plants, including conifers, are cone-bearing seed plants that typically have needle-, awl-, and/or scale-shaped leaves. The needle-, awl-, and/or scale-shaped leaves have small surface areas. Thus, each needle captures a small amount of light energy. The gymnosperm leaf also has a thick cuticle layer and pit-like stomata that reduce water loss. Gymnosperm plants are well adapted to cold climates coupled with frequent snow and drier climates. Coniferous plants are usually evergreen (e.g., spruce, pine, fir), although some species are deciduous (e.g., larch, baldcypress, metasequoia).

Evergreen leaves of conifers last for three to four years before being shed. This gives these plants an advantage over broadleaf deciduous plants. The metabolic cost of producing and retaining leaves is recovered via photosynthesis over several growing seasons as opposed to the single season of deciduous plants. In addition, photosynthesis can take place in evergreen leaves whenever environmental conditions are not too cold. These plants can photosynthesize even in the middle of winter.

A German study compared the energy production of the beech tree (broadleaf deciduous) to the Norway spruce tree (needle-shaped leaves, evergreen). It was found that the beech photosynthesizes 176 days in a year. The Norway spruce photosynthesizes 260 days in a year. The leaves of the Norway spruce have small surface areas. However, they have a longer period for photosynthesis. In the end, the Norway spruce was 58 percent more productive than the beech.

## LEAF ABSCISSION

Most deciduous plants are found in temperate regions of the world. In those areas, summers are warm and winters cold. As winter approaches, leaves turn color and leaf abscission occurs. **Abscission** means the shedding of plant parts, including leaves, flowers, and fruit.

During the growing season, the leaves of broadleaf plants lose a tremendous amount of water through transpiration. As long as there is available soil moisture, water can be absorbed by the roots and translocated upward. As soil temperatures drop with the onset of colder weather, root activity slows. Plant metabolism also slows greatly, reducing the need for water. When the ground freezes, roots are simply unable to absorb any water, as it is in solid form. Thus, it is advantageous for plants to shed their leaves before winter arrives.

If deciduous plants were to retain their leaves in the winter, the leaf tissues would likely die of extreme desiccation. **Desiccation** is dehydration or the severe loss of water from plant tissue. Desiccation, also known as winter burn, is a problem with evergreens. Conditions that lead to desiccation are low soil moisture, freezing temperatures, and blowing wind. Under these conditions, plants lose moisture through transpiration faster than their roots can replace it from the cold ground.

Many physiological changes regulated by hormones are associated with leaf abscission. As fall gets closer, a plant withdraws essential minerals, such as nitrogen and phosphorus, from the leaf tissues and relocates them to the stem and roots. Starches in the leaves are converted to sugars for relocation to other parts of the plant. This process elevates sugar levels in the leaf tissues. Green pigmented chlorophyll is broken down. As a result, the yellow, orange, red, and purple accessory pigments, including carotenoids and anthocyanins, that were once masked by the chlorophyll become visible.

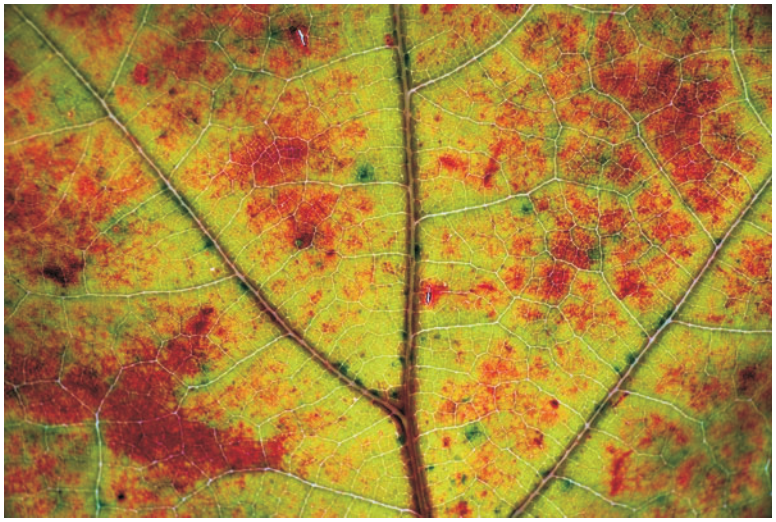

**FIGURE 5. The colorful carotenoids are revealed in autumn leaves as the chlorophyll pigments die off.**

## Exploring Our World... *SCIENCE CONNECTION*

### Fall Color

In much of the country, the turning of leaves from green to reds, yellows, and purples is one signal that winter is coming. In some years, the fall colors are spectacular. In other years, the fall colors are mediocre. Why? Fall color is determined by plant genetics and the environment.

A warm and wet spring, favorable summer weather, and warm, sunny fall days with cool nights tend to produce the most brilliant autumn colors. As the days grow shorter and the weather gets cooler in the fall, trees begin to slow the production of new chlorophyll, and existing chlorophyll breaks down. As the influence of chlorophyll pigments diminishes, other pigments, including carotenoids and anthocyanins, become more visible.

A fall season with sunny days and cool, crisp but not freezing nights promotes the production of sugars in the leaves, but the cool nights and the gradual closing of leaf veins prevent these sugars from being translocated out of the leaves. Lots of sugar and lots of light stimulate the production of anthocyanin pigments, which are red, purple, and crimson.

The two-tone effect on some trees that exhibit yellow leaves toward the inside or bottom and red or purple leaves on the outside or top is caused by greater exposure to sunlight on the upper and outer leaves.

The actual area where a leaf separates from the plant is called the abscission layer or abscission zone. The **abscission layer** is a layer of loosely connected, thin-walled parenchyma cells that forms at the base of a petiole; the weak cell walls break, allowing the leaf to fall.

As autumn progresses, a layer of cork cells forms on the stem side of the abscission layer. The cork cells secrete suberin, which is impermeable to water. Plant enzymes work to dissolve the intercellular material that holds the abscission-layer parenchyma cells together. The abscission layer breaks down to a point where only a few xylem cells hold the leaf to the stem. Eventually, these give way, and the leaf falls. The remaining layer of cork cells serves as a protective barrier and forms the leaf scar.

## MODIFIED LEAVES

Leaves sometimes take on functions other than photosynthesis.

Leaves may serve to protect the plant. Hard, sharp spines found on cacti are actually modified leaves that deter animals. The green photosynthetic organ of cacti is the stem.

Leaves may help support a plant. Climbing vines, such as grapevines and cucurbits (e.g., pumpkin, squash, cucumber), have specialized leaves called tendrils that attach to structures. The tendrils help by supporting the weight of the vines.

**FIGURE 6. Tendrils are modified leaves that help support a plant.**

Leaves protect dormant buds. Bud scales are modified leaves that enclose meristem tissue and protect it from injury and desiccation during winter months.

**FIGURE 7. Bud scales are modified leaves that enclose meristem tissue and protect it from injury and desiccation during winter months.**

Leaves may take on the role of storage. A bulb, such as an onion, consists of a short stem with numerous fleshy leaves modified to store food and water.

Leaves of insectivorous plants are modified to trap prey. Venus flytraps and pitcher plants are two examples. These plant species are adapted to living in acidic soils with low nutrient content. Their way of compensating for low soil nutrients is to trap animals, mostly insects, in their modified leaves, digest the animals, and absorb mineral nutrients.

Some modified leaves are called bracts. A **bract** is a modified leaf lacking axillary buds and different in size, form, and/or color from the foliage leaves associated with a flower, inflorescence axis, or cone scale. Bracts protect the flowers from pests and harsh weather. The brightly colored bracts of poinsettias take on the role of attracting pollinators in place of colorful petals or tepals. Other bracts, such as those of passion flowers, are coated with a sticky substance that traps insects.

**FIGURE 8. The brightly colored bracts of poinsettias take on the role of attracting pollinators in place of colorful petals or tepals.**

## Summary:

A leaf is a plant organ that collects solar energy and converts it to food. Leaves of angiosperms are flattened to make the most of light absorption and the exchange of gases.

A flattened leaf has two epidermal layers, the upper epidermis and the lower epidermis. The epidermis consists of parenchyma cells. Cuticle, trichomes, guard cells, and bulliform cells are associated with the epidermis.

Between the epidermal layers is the primary photosynthetic tissue called the mesophyll. The mesophyll consists of parenchyma cells organized into the palisade layer and the spongy mesophyll layer. Mesophyll tissue contains chlorophyll, carotenoids, and anthocyanins.

Throughout the mesophyll is a network of veins consisting of xylem and phloem tissues. Veins are numerous enough so every cell is reached for exchange of materials. Veins are encircled by a bundle sheath.

Abscission means the shedding of plant parts, including leaves, flowers, and fruit. The actual area where a leaf separates from the plant is called the abscission layer.

Leaves sometimes take on functions other than photosynthesis, such as protection, support, storage, trapping of animals for nutrition, and attraction of pollinators.

## Expanding Your Knowledge:

Watch the YouTube video, "Leaf Structure," at https://www.youtube.com/watch?v=O62Muz6kV3o&t=2s. As you view it, think about the topics discussed in class and presented in this E-unit.

## Checking Your Knowledge:

### Part One: Matching

*Instructions:* Match the term with the correct definition.

| | |
|---|---|
| a. abscission | f. guard cell |
| b. abscission layer | g. palisade layer |
| c. bulliform cell | h. spongy mesophyll layer |
| d. bundle sheath | i. stoma |
| e. cuticle | j. trichome |

_______1. one of a pair of cells that regulate the opening and closing of the stoma, through which the diffusion of carbon dioxide, oxygen, and water vapor is allowed

_______2. a tiny pore in the epidermis that regulates the exchange of gases

_______3. a large, bubble-shaped epidermal cell found in groups on the upper surface of a monocot leaf near the mid vein

_______4. the shedding of plant parts, including leaves, flowers, and fruit

_______5. a tight stratum of vertically arranged mesophyll cells lying just below the upper epidermis

_______6. a waxy substance that covers the outer epidermal surface and functions to reduce water loss through evaporation and to prevent external water and solutes from entering the leaf

_______7. a layer of loosely connected, thin-walled parenchyma cells that forms at the base of a petiole; the weak cell walls break, allowing the leaf to fall

_______8. a long, narrow epidermal cell that grows perpendicular to the surface

_______9. a loosely arranged layer of cells beneath the palisade layer that is interspersed with an open intercellular system

______10. one or more layers of parenchyma or sclerenchyma cells wrapped around vascular tissue with the functions of regulating the movement of substances between the vascular tissue and the mesophyll and protecting the vascular tissue from exposure to air

### Part Two: Completion

*Instructions:* Complete the following statements.

1. A __________________________ leaf has a broad, flattened blade connected to the stem by a petiole and displays netted venation.
2. A __________________________ is a plant organ that collects solar energy and converts it to food.

3. The epidermis consists of ________________________ cells that lack chloroplasts and are fairly transparent to allow the transmission of light.

4. ________________________ is the primary pigment involved in photosynthesis and is the most efficient light-capturing pigment.

5. ________________________ are supplementary pigments that absorb energy from green-violet wavelengths.

6. The ________________________, which delivers water and dissolved minerals to the leaf tissues, is located on the upper side of the vein.

7. In $C_4$ plants the ________________________ cells contain chloroplasts and are the site of the Calvin cycle.

8. As autumn progresses, a layer of ________________________ cells forms on the stem side of the abscission layer.

9. Climbing vines, such as grapevines, have specialized leaves called ________________ _________ that attach to structures.

10. ________________________ are modified leaves that enclose meristem tissue and protect it from injury and desiccation during winter months.

## Part Three: True/False

*Instructions:* Write *T* for true or *F* for false.

_______1. Dicots have long, narrow leaves that lack petioles and are typified by veins running parallel to one another.

_______2. In the case of desert plants, trichomes may protect the leaves from high light intensity.

_______3. Stomata are more prevalent on the upper epidermis than the lower epidermis.

_______4. Guard cells are unique epidermal cells in that they contain chloroplasts.

_______5. Cells of the spongy mesophyll layer contain three to five times as many chloroplasts as those of the palisade layer.

_______6. Anthocyanins belong to a class of molecules called flavonoids and are generally produced toward the end of summer.

_______7. The petiole is encircled by a bundle sheath.

_______8. In a deciduous plant, a layer of cork cells form on the top side of the abscission layer.

_______9. Cuticle is secreted during leaf abscission and serves as a protective barrier over the leaf scar.

______10. Spines found on cacti are actually modified leaves.