frontiers FOR YOUNG MINDS

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WHAT IS A LEAF?

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YOUNG REVIEWERS:


CAMILLE
AGE: 9


ELLE
AGE: 11


JACK
AGE: 13


JOSI
AGE: 9


SOPHIA
AGE: 15

When thinking of plants, the color green inevitably comes to mind. As perhaps the most noticeable and easily recognizable part of the natural world, leaves decorate the world green. If you take a close look at the plants in your yard or on your street, it is likely that you will not find two that are exactly the same. This is largely thanks to the enormous amount of diversity that exists in leaf shapes, textures, and even colors! All leaves share general characteristics that we will review in this article, but some have taken on special abilities. Some leaves are modified to look like flowers, others are modified to help the plant climb, to protect the plant from potential threats, or even to act as insect traps. We want to share with you the extraordinary world of leaves: keep reading, and you will learn the many shapes, structures, and incredible functions of leaves.

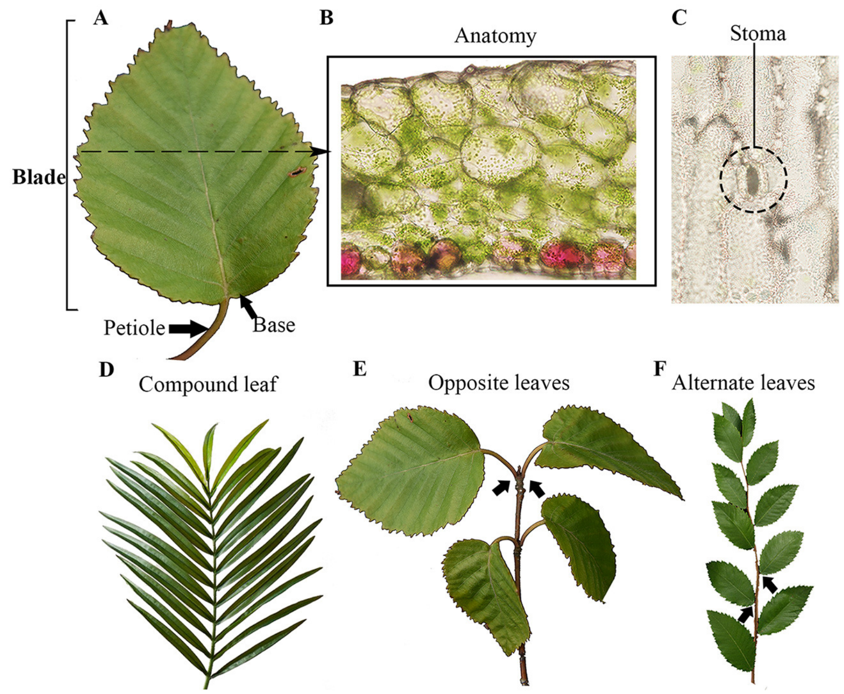

Figure 1

Figure 1

External and internal structure of the leaf. **(A)** The top side of leaf. Here, the petiole connects the leaf to the stem. **(B)** A cross section of this leaf shows the various cell layers; green specks inside the cells are chloroplasts. **(C)** Stomata, structures that open and close to allow gas exchange with the environment. **(D)** A compound palm leaf, composed of multiple leaflets. **(E)** Opposite leaves, growing directly across from each other on the stem. **(F)** Alternate leaves growing one after the other on the stem.

WHAT CONSTITUTES A LEAF?

Leaves are constructed of three major parts: the **petiole**, the **base**, and the **blade** (Figure 1A). Generally, the largest portion of the leaf is the blade. The base is the region of the blade that attaches to the petiole, a stalk-like structure that connects the blade of the leaf to the stem of the plant. Some leaves lack petioles and are known as sessile (immobile) leaves.

The leaf blade is formed of multiple cell layers. Plant cells are relatively big, and enclosed by a cell wall (Figure 1B). Leaf cells are filled with **chloroplasts**, structures that contain specialized pigments called **chlorophylls**. Chlorophylls absorb light, allowing plants to collect energy from the sun. Leaves are green because chlorophylls absorb every color of UV light except for green. By not absorbing green, they reflect it instead, which our eyes then see. Leaves have a waxy outer layer covered with **stomata**, which are like mouths that open and close to allow gas exchange with the environment (Figure 1C). Leaves must strike a balance between opening their stomata enough to allow for gas exchange and keeping them closed to prevent water loss.

Leaves have veins that run through the petiole to the rest of the plant. These veins are made of **vascular tissues**, which are the structural tissues that transport water and nutrients to all parts of the plant. If you forget to water your plant for a few weeks, you may notice the leaves start to wilt. If you add some water to the soil, however,

PETIOLE

The stalk that connects the leaf blade to the stem or meristem of the plant.

BASE

The region of the leaf blade that connects to the petiole.

BLADE

The broad portion of the leaf, which is also sometimes referred to as the lamina.

CHLOROPLAST

An organelle in plant cells that is the site of photosynthesis.

CHLOROPHYLL

The pigment that absorbs and captures energy from the sun.

STOMATA

Pores on the surface of plant tissues (such as leaves) that allow gas exchange with the environment.

VASCULAR TISSUES

Plant tissues that transport water up and down the plant body.

the water will be transported all the way to the leaves, making them upright again.

Leaves can be large or small, symmetrical or asymmetrical, have jagged or smooth edges, and appear glossy or rough. Leaves are broadly classified into two types. Simple leaves are composed of a single blade. Compound leaves are composed of multiple blades, which are called leaflets. Leaf arrangement on the stem can be opposite, such as when two leaves grow directly across from each other, or alternating, when leaves alternate sides, one after the other (Figures 1D–F).

THE LIFE CYCLE OF A LEAF

Many leaves develop in protected structures called leaf buds. New leaves are enclosed by protective scales that allow the fragile leaves to rest until they are ready to expand. These scales are modified leaves that do not photosynthesize. Some buds lack these protective scales and are called naked buds [1].

Throughout their lives, leaves expand in size and may also change color. In some parts of the world, the fall season is known for piles of orange, yellow, red, and brown leaves. In the fall, leaf cells accumulate more light-absorbing pigments called **carotenoids**. Carotenoids reflect colors such as yellow and orange. These pigments are normally at lower concentrations than chlorophyll, so they are usually masked by the green color. Trees can assess temperature and the length of daylight. As both decrease during the fall, chlorophyll starts to degrade, and the yellows and oranges of the carotenoids can shine through [2].

CAROTENOID

Pigments that absorb light and reflect color.

When trees lose their leaves, they are not dying. Before the leaves fall, trees shuttle nutrients away from the leaves to other parts of the plant, to store those nutrients for later use. Changes in the leaves weaken the bond between the petiole and the stem, and eventually the leaves naturally part with the tree. You may have heard the term "evergreen tree," referring to trees that stay green during the winter. Some evergreen conifers (such as pine trees) keep their leaves for at least an entire year before gradually shedding older needles to make way for new ones.

LEAF FUNCTION

As plants cannot move, they cannot go to the kitchen and make a sandwich when they feel hungry. Instead, they produce their own food. Organisms that do this are called "**autotrophs**." Leaves serve as the main location for food production through a process called photosynthesis, which occurs in the chloroplasts. During

AUTOTROPH

An organism that produces its own food ("*auto*" = self, "*troph*" = food).

PHOTOSYNTHESIS

The process by which energy from the sun, carbon dioxide, and water are converted into plant food.

photosynthesis, light, water, and carbon dioxide from the atmosphere are absorbed and converted into energy in the form of sugars. As a result of photosynthesis, water is split into hydrogen and oxygen. Plants release the extra oxygen through the stomata, which contributes to the air we breathe. The structure of the leaf is perfectly engineered for its role in photosynthesis. The blade is composed of cells filled with chloroplasts that capture light during the day. In most plants, stomata are more numerous on the underside of the leaf, to reduce water loss while performing gas exchange.

Plants release many other molecules that interact with the environment. Some plants release signals when they have been damaged. For example, the sweet scent of freshly mowed grass is a signal of distress as well as a defense mechanism to herbivore attacks. Signals like these can either attract predatory species for the herbivores, attract beneficial insects (like parasitic wasps that fend off the herbivores), or warn neighboring plants to build up their chemical defenses [3].

Some leaves are modified for functions other than photosynthesis. For instance, in climbing plants like cucumbers, some leaves coil and form tendrils, which help the plant attach to a support as it climbs (Figure 2A). Sometimes leaves trick us into thinking that they are part of the flower, by doing an excellent job impersonating petals (Figures 2E,F). An example of this is found in hydrangea blooms. Referred to as bracts, these modified leaves extend under the true flower. Their showy color attracts pollinators to the flowers they are supporting (Figures 2E,F). Next time you see a hydrangea, see if you can distinguish the bracts from the true flowers. Cacti spines are also leaves that have been severely reduced to protect the plant with their sharp and pointed shapes (Figure 2D). In cacti, photosynthesis occurs in the green stems. In carnivorous plants, rolled leaves act as insect traps, either by creating a long pitcher shape that contains enzymes or bacteria that digest insects, or by rapidly snapping shut around an insect. The leaves of carnivorous plants are usually vibrantly colored to attract insects (Figures 2B,C).

EVOLUTION OF THE LEAF

The first plants on land more than 400 million years ago were bryophytes, which include mosses, hornworts, and liverworts [4]. These small plants lack vascular tissues completely and they do not have leaves or roots. For example, if you look really closely at moss, you may observe small, green, leaf-like structures; however, these are not true leaves because they lack vascular tissues. True leaves first evolved in vascular plants, which include the lycophytes, ferns, and seed plants. There are several hypotheses as to how leaves evolved. They may have evolved from plant branches that became flattened and fused, leading to the structure we now know as the leaf; or leaves may have evolved

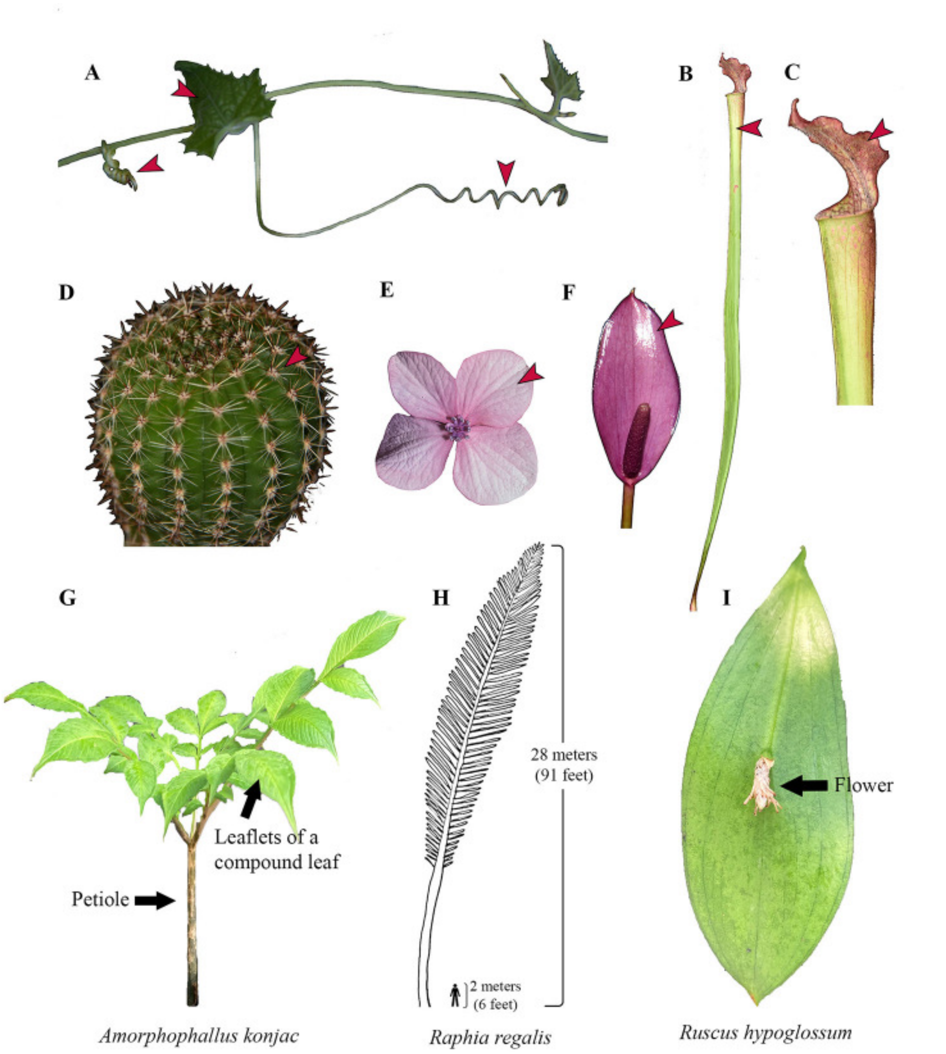

Figure 2

Figure 2

Examples of modified leaves. Red arrowheads designate leaves. **(A)** Tendrils in cucumber plants. **(B)** Rolled leaf of a pitcher plant, modified to trap insects. **(C)** Close-up of the top of the leaf in a pitcher plant. **(D)** Cactus spines. **(E)** Pink Hydrangea bracts extending beneath the flowers. **(F)** Anthurium bract, colorful to attract pollinators. **(G)** A juvenile compound leaf of *Amorphophallus konjac*, which can reach 4–5 ft in height at maturity. **(H)** *Raphia regalis*, one of the largest known leaves. Size of a leaf is given relative to height of a person. **(I)** *Ruscus hypoglossum* with flowers on the leaf.

from plant reproductive structures [4]. It is now accepted that leaves have evolved independently in several plant families. By studying fossils and DNA, evolutionary biologists are still investigating how many times leaves evolved independently.

DISTINCTIVE LEAVES

Some plants have very unique leaf structures [5]. For example, some plants have only one solitary leaf. *Amorphophallus konjac* develops a single compound leaf each year, with the petiole extending into the ground, such that the leaf appears like a small tree (Figure 2G). Another distinctive leaf is from *Raphia regalis*, one of the longest leaves in the world, with one leaf having a recorded measurement of 28 m (91 feet) (Figure 2H) [5]. Imagine a leaf about the same length as a basketball court! Another unique leaf is from *Ruscus hypoglossum*, which has its flowers located on top of the leaf blade (Figure 2I).

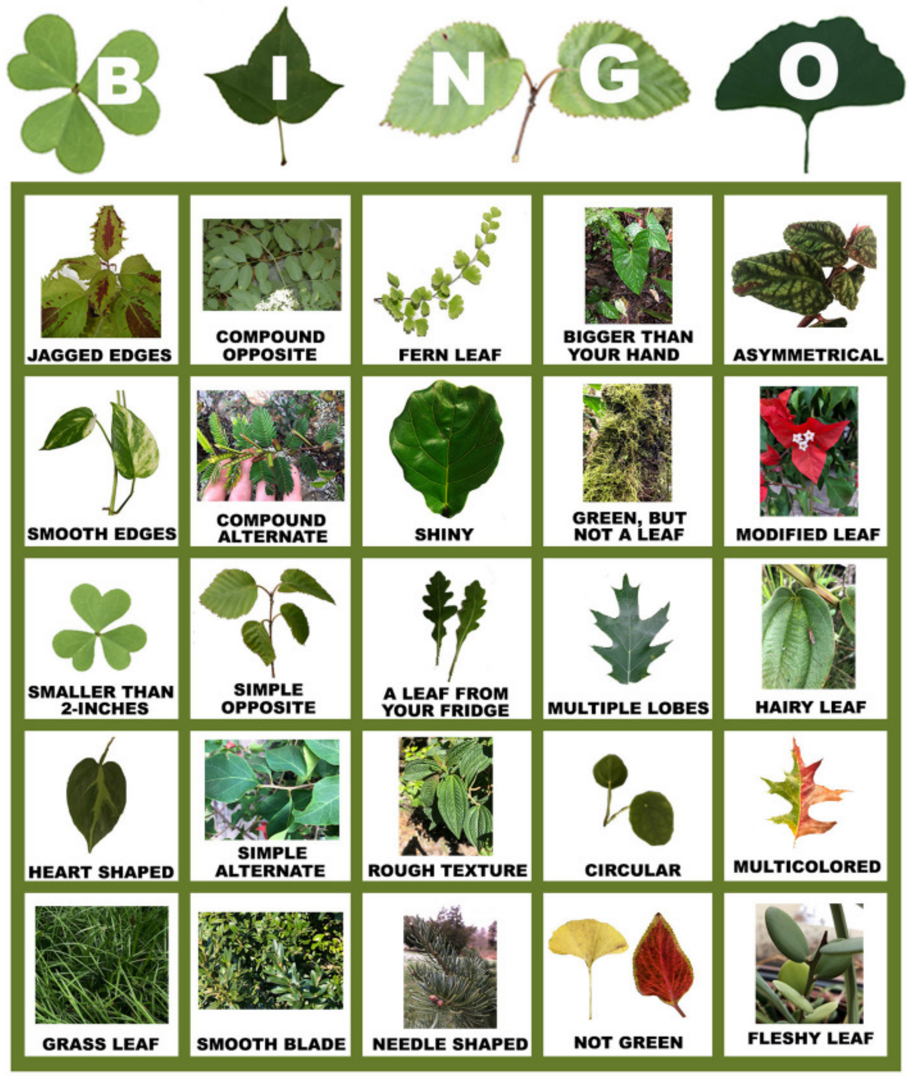

Figure 3

Figure 3

Leaf bingo showing leaf diversity. When you next spend some time outside, look for leaves that fit these descriptions and cross them off on this card. When you have filled in five in a row, column, diagonal, or even the entire card, you can call out "BINGO!"

LET US OBSERVE TOGETHER!

Now you know that there is lots of diversity in leaf structure and function that contributes to keeping plants alive and healthy: leaves come in many shapes and sizes, and their role extends beyond just performing photosynthesis (Figures 1, 2). It is always a great time to go outside and collect leaves, even in the winter! We created a leaf bingo for you to use the next time you go outside (Figure 3). How many different types of leaves can you find? Have fun!

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YOUNG REVIEWERS

CAMILLE, AGE: 9

I am 9 years old. I love to read everything, but I especially like fantasy books. My favorite books are *Warriors* and *Wings Of Fire*. I love to draw and write about cats and dragons too. I like to play card and board games with my family. My science interests are Geology, Zoology, and Biochemistry.

ELLE, AGE: 11

My name is Elle, and I just turned 12 years old. I love cats, and wish I had one of my own. I love to dance, write, sing, read, and draw. I would like to become a lawyer when I am older. My favorite subjects in school have always been ELA and history. I have participated in the science fair all of my life, and I enjoy watching videos and reading articles to better understand the world around me. Fashion is a passion of mine too.

JACK, AGE: 13

My name is Jack. I am interested in coding, programming, and cybersecurity. I participate in science and math competitions like Science Olympiad and Math League. I am an avid basketball player. I love to travel and have visited 4 of the 7 continents so far.

JOSI, AGE: 9

My name is Josi. I love to read and write stories. My favorite animals are pigs because they are really cute. Pink is my favortite color. Science is one of my favorite subjects along with math. For my science project this year, I explored the physics of a scooter because riding my scooter is a favorite activity of mine.

SOPHIA, AGE: 15

My name is Sophia. I am on the pre-med pathway in high school. I compete in Science Olympiad, Quiz Bowl, and the Science Fair. I have a love for spelling. I won my school spelling bee multiple years and competed in the Scripps national spelling bee. For relaxation, I enjoy doing art projects and baking culinary treats for my friends and family. I also love to travel. One of my favorite places is Tokyo.

AUTHORS

ELLIE MENDELSON

I am broadly interested in evolutionary developmental biology, and how the evolution of complex structures has contributed to how plants interact with each other and the environment. I received my undergraduate degree in biology from Brandeis University, where I collaborated with the Ambrose Lab at the New York Botanical Garden to write a senior thesis about the genetic network of fruit development in early diverging angiosperms. Currently, as a research assistant in the Friedman Lab at the Arnold Arboretum of Harvard University, I am contributing to various projects related to plant evolution and morphology. In my spare time, I like to watercolor and spend time outside.

CECILIA ZUMAJO-CARDONA

I have always been fascinated by plants and the enormous diversity of shapes, colors, and structures that allow them to be so successful and important for our entire ecosystem. I became interested in understanding the genes involved in that diversity while doing my undergraduate work at the Universidad de Antioquia (Colombia) in the Pabón-Mora lab, where I looked at genes involved in fruit development. I obtained my Ph.D. from the New York Botanical Garden and the City University of New York in the Ambrose Lab, mainly working in seed evolution and development in the first plant lineages that appeared with a seed (like pine trees) to better understand the genes underlying the vast diversity of seed shapes.

BARBARA A. AMBROSE

I am the director of laboratory research and associate curator of plant genomics at the New York Botanical Garden. I investigate the molecular genetic basis of plant diversity. I use scanning electron microscopy and histological sections as well as molecular tools in my research. Although I investigate the evolutionary genetics of flowers and fruits, most of my current research is focused on the evolution and development of lycophytes and ferns. My evolutionary developmental research at NYBG is enhanced by the expertise of garden scientists in the structure of lycophytes, ferns, and seed plants. *bambrose@nybg.org