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WHY ARE SOME PLANTS HAIRY?

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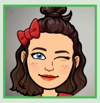
YOUNG REVIEWERS:

DARIO
AGE: 15

SRIJA
AGE: 13



VALERIE
AGE: 14

Whether we live in a sprawling metropolis or on a rural farm, plants and insects are part of our daily lives, and many of them cannot exist without the other. Insects help plants reproduce *via* pollination, and plants provide insects with food and shelter. However, plants also require nutrition to grow, develop, and reproduce; and plant-eating insects can damage them. Over millions of years of living together, plants have evolved multiple defense strategies to defend themselves against insects. One such defense is tiny hair-like projections called trichomes. In this article, we explain how plants use their trichomes as a creative and unique weapon to protect themselves from insect herbivores. Trichomes can cause physical injury, release toxic chemical compounds, and even cause internal injury to insects. We also discuss how plant-eating insects counter these plant defenses using their own defenses—leading to a tug-of-war for survival.

WHY ARE PLANTS SO IMPORTANT?

Plants, the backbone of planet Earth, are widely thought to be nothing more than stationary, uninteresting organisms. However, studying plants has revealed how complex and interesting they are, and plant research has taught us about the vast array of physical and chemical characteristics plants use to thrive on Earth, where they are surrounded by organisms that feast on them. Plants are not just food sources for animals—they also shape the environment around us in many ways, and most other organisms could not survive without them. For example, plants take up carbon dioxide (CO_2), a gas that animals exhale or produced when burning fossil fuels, and use it in **photosynthesis**. This removes CO_2 from the atmosphere. Without the removal of CO_2, life on Earth would be impossible. As you may know, the excess of CO_2 in the atmosphere is causing environmental problems like global warming [1]. Also, when it comes to farming, plants called cover crops minimize the effects of soil erosion, by holding the topsoil in place *via* their root structures. This helps to keep soil heathy. However, to perform these **ecosystem services**, plants must thrive well in various environments and protect themselves against their mortal enemies, the **herbivorous** insects. These insects damage and even kill plants by feeding on plants' leaves, flowers, fruits, and roots.

PHOTOSYNTHESIS

Biological process by which plants make and store food, in the form of sugars.

ECOSYSTEM SERVICES

Actions done by organisms in the benefit of the ecosystem.

HERBIVOROUS

Plant eating.

INSECTS AND PLANTS

Insects, regardless of their relatively small size, are extremely important organisms in the animal kingdom. The diversity of insects is unmatched, with many feeding on animals and others dependent upon plants. Many species of insects rely solely on plants for food (Figure 1), and others only feed on plants during certain parts of their lifecycle. Think about a caterpillar hatching from its egg on a leaf surface, feeding on the plant until it is ready to form a pupa, then attaching itself to the plant or burrowing into nearby soil until it is ready to emerge as a moth or butterfly. To outsmart each other, plants and insects have been co-evolving for millions of years and, in many cases, they cannot live or reproduce without each other. While many insect species feed on plants, plants also depend on insects for reproduction, through **pollination**. Without insects, many plant species would cease to exist. But how can plants thrive on Earth if the number of insects, many of which constantly feed on plants, heavily outweighs them?

POLLINATION

Transfer of pollen from plant's male reproductive organs to the plant's female reproductive organs.

PLANT DEFENSES AGAINST INSECTS

Plants are mostly immobile and appear defenseless to the untrained eye, but a deeper look can show us a wide range of both chemical and physical defenses that plants employ to protect themselves

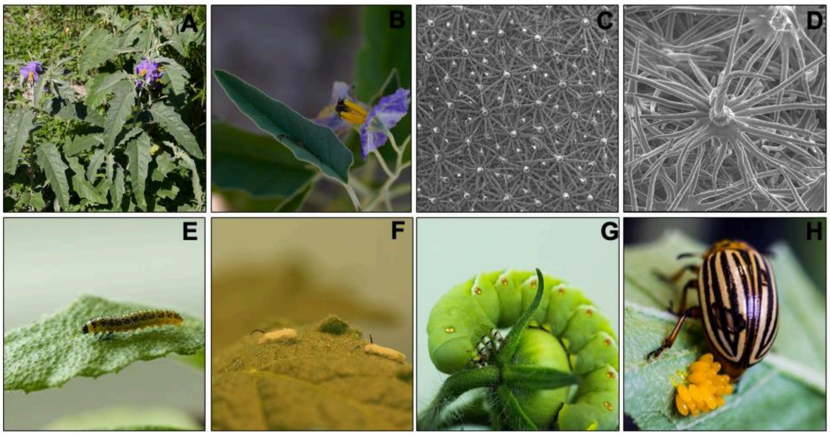


Figure 1

Figure 1

(A) Picture of silverleaf nightshade (SLN) plants sprouted in the field as weed. **(B)** Magnified image of SLN leaf. **(C)** Scanning Electron Microscopy (SEM) image of same leaf at 100X, with visible trichomes (hairs). **(D)** Enlarged image of single trichome highlights the pointed structure of trichome with one spiled head and pointed parts (roughly 25) which are responsible for poking holes on insects pests feeding on plant. **(E)** Tobacco hornworm caterpillar on a horsenettle plant. **(F)** A bordered patch butterfly caterpillar on a sunflower plant. **(G)** A cabbage butterfly caterpillar on a thale cress leaf. **(H)** A fall armyworm caterpillar on a tomato plant. All the host plants have trichomes that vary in type and density. (Image credits: Rupesh Kariyat and Ishveen Kaur).

against the insects ready to feed on and possibly decimate them. Plants have chemical defenses that are invisible to us, which they use to deter insects from mindlessly chowing down on them. These defenses include the emission of **volatile compounds** that attract other organisms that feed on insects, indirectly protecting the plant [2]. Some plants are toxic or taste terrible, thereby directly defending themselves against insects.

In addition, as you may have noticed, some plants are armed with thick spines that we can see and—even worse—feel. Plants also have physical defenses that are not so easily noticed. Herbivorous insects, like the caterpillar that just hatched from its egg, must find a spot on the leaf surface to start feeding. Here is where the plant's first line of defense is waiting—plant hairs called **trichomes** (Figures 2E,F). We often think of animals as the only organisms with hair or fur, yet an estimate 80% of plants also have hairs on many of their structures.

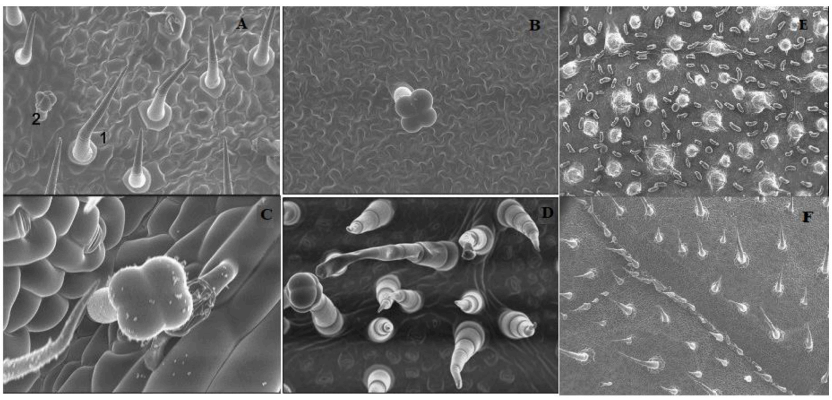


Figure 2

Figure 2

SEM image of **(A)** bottle gourd at 400× magnification, showing non-glandular (1) and glandular (2) trichomes. **(B,C)** A glandular trichome magnified at 600× and 800×, respectively. **(D)** The same leaf at 450×. Bulky, globular, glandular trichomes housing chemical toxins (1) and hook-shaped, non-glandular trichomes (2) can be seen. **(E)** Sunflower leaf at 200×. **(F)** Squash leaf at 100×.

HOW PLANTS USE TRICHOMES TO DEFEND AGAINST INSECTS

Trichomes are present on various parts of plants, such as leaves, stems, and fruits, and these hairs function as a formidable barrier against a wide range of herbivorous insects—in truly fascinating ways. But trichomes have other functions, too. For example, if it is extremely hot, they act as a canopy to produce shade, reduce water loss, and protect the plant against the sun's ultraviolet radiation. But their protection function against insects is the most interesting part. Plant trichomes have tremendous variation in size, shape, and numbers (Figure 2). A mat of trichomes on the leaf surface can delay caterpillar feeding in a density-dependent manner [3], which means that, if a plant has more trichomes, it takes caterpillars longer to find a spot or to chew through the trichomes to get to epidermis—the first nutritious leaf layer. Some trichomes are also sharp, and they can poke holes in the soft bodies of caterpillars (Figures 2A,D). Surprisingly, some plants can even increase the number of trichomes on young leaves if their older leaves are being eaten—preparing the young leaves against future damage!

VOLATILE COMPOUNDS

Chemical compounds released by plants, in this case to alert the predators of the insects that are attacking the plants.

TRICHOMES

Hair-like protrusions used by plants for defense.

Broadly speaking, trichomes are divided into two types: non-glandular and glandular. **Non-glandular trichomes** are sharp, pointed, spiny appendages that hinder the movement of herbivorous insects by acting as a physical barrier (Figures 2A,D) [4, 5]. In many cases they look like stars. These sharp needles are also fortified with hard substances like silica and calcium carbonate, which can blunt the teeth of caterpillars, making it difficult for them to chew. In addition to restricting the ability of caterpillars to feed, trichomes are also destructive once they enter the caterpillar's gut. They poke holes in the gut wall, which causes the food to mix with the blood. This can lead to dangerous infections and activate the caterpillar's immune system [6].

NON-GLANDULAR TRICHOMES

Type of trichomes that primarily deter insects by mechanically stopping them from attacking the plant.

Glandular trichomes, in contrast, have swollen globular heads (like water tanks) that contain toxic or sticky compounds that can either trap herbivores or kill them when ingested (Figures 2A–C). In some cases, these globular heads can also produce foul-smelling compounds that repel herbivores. Thus, we can say that these mini water tanks splash toxins as soon as they get a danger signal from any kind of insect attack. In summary, trichomes—the harmless-looking hairs on plant leaves—can protect plants in multiple ways before, during, and after attack by caterpillars or other insects.

GLANDULAR TRICHOMES

Type of trichomes that contain toxins or substances that are harmful to insect predators.

HOW DO INSECTS DEAL WITH THIS "HAIRY" PROBLEM?

Does this mean that plants win the battle against insects very easily? Not really. Insects have co-evolved in multiple unique ways to battle plant defenses. Some insects can shave trichomes off plant parts, like lawn mowing. If you carefully watch a tobacco hornworm caterpillar on a tomato plant, you will see that it navigates along the leaf surface until it finds a good spot with fewer trichomes, or it travels along leaf edges to avoid them. Some insects, like the tiger clearwing butterfly caterpillar, weave silk fibers over the trichomes to create a smooth surface that helps them to walk across a rough patch on the leaf. The digestive systems of some caterpillars allow them to eat trichomes without any toxic effects, so they can still feed on those plants [7]. Still other insects form a thick layer of secretions over trichomes, preventing direct contact of insects to trichomes [8].

WHY DO WE STUDY THESE "HAIRS"

In summary, trichomes have diverse functions, and their unique structures have the potential to protect plants in several different ways against the herbivores that want to feed on them. However, some insects have co-evolved unique ways to get around these plant defenses. This is fascinating because it clearly depicts how plants and insects outcompete each other in an evolutionary race for survival, alongside the ways we can manipulate trichomes to protect plants making it an interesting area of research. Moving forward, it would be interesting for scientists to study the role of each type of trichomes in more depth, to understand why there are such wide variations in the density and type of trichomes across plant families. Maybe this variation helps plants defend themselves against various insect groups. For example, what if a stink bug is feeding on a plant, instead of a caterpillar, would different types of trichomes help more against one insect or the other? As pest species become more prevalent as a result of global climate change, we need to better understand how trichomes work together to protect plants, as it will help us to devise integrated pest management strategies to control harmful pests feeding on agricultural crops.

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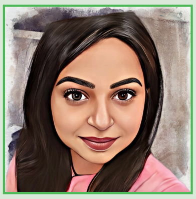
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

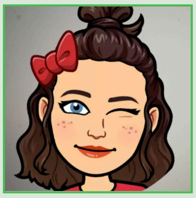
DARIO, AGE: 15

My name is Dario. I live in a small village in Austria. It is full of nature so in my freetime I like to go out with my dogs or climb trees. My parents are both biologist so I got into biology pretty early.



SRIJA, AGE: 13

Hi! My name is Srija and I am fun loving girl and I love painting and playing chess!



VALERIE, AGE: 14

I am in 9th grade of a middle school in Austria. My hobbies are horseback riding, skating and dancing. I have got a very old cat and we are getting a dog soon. I also like meeting my friends and listening to some music.

AUTHORS

ALEJANDRO R. VASQUEZ

Hi! I am Alejandro, I am a Masters (Entomology focus) student who loves plants and insects, as well as the environment! I have always been passionate about science and discovery and understanding the quirky and unique things about the living things around us, by looking for the unexpected in every aspect of living organisms!

ISHVEEN KAUR

Hi! I am Ishveen. I am a Ph.D. Student in Biological Sciences, and I am passionate about plants and insects. I am curious to learn about plant based bioactive compounds, and their roles in defending against environmental vagaries and how these compounds affect health of living beings, thereby linking plant science to animal and human health.

RUPESH KARIYAT

I am an Associate Professor of Crop Entomology at University of Arkansas. As a scientist, I am interested in understanding how insect herbivores defend against plants and their how they counter plant defenses to successfully feed and develop. As a long-term goal, my lab is focused on using the knowledge from studying insect plant interactions to devise sustainable pest management strategies.

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