frontiers FOR YOUNG MINDS

EARTH AND ITS RESOURCES
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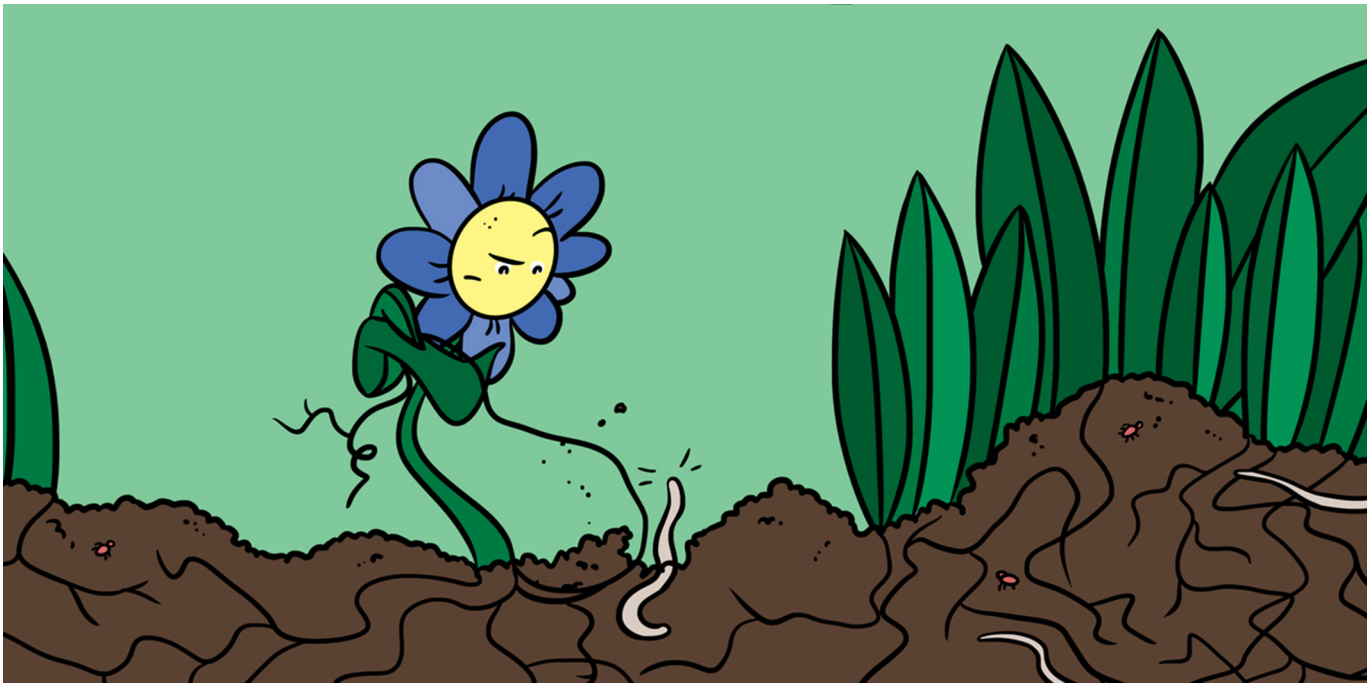

HOW DO PLANTS DEFEND THEMSELVES FROM ROOT-EATING CREATURES?

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CATHERINE
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HARRISON
AGE: 11

The belowground world is full of creatures that depend on plants as a food source. Belowground plant eaters, or herbivores, feed on roots and can cause considerable damage to plants. Roots are very important because they help plants take up water and nutrients from the soil. These are important resources that plants need for growth. To protect their roots, plants produce chemical defenses. The production of these defenses is costly because nutrients and energy used to make defenses cannot be used for growth or the production of flowers and seeds. Plants, therefore, must be efficient with their defenses. Scientists are very interested in understanding how plants defend themselves efficiently, because this can help us to develop more environmentally friendly ways of growing fruits and vegetables. In this article, we explain how plants defend themselves efficiently, and how plant defenses affect herbivores in the soil.

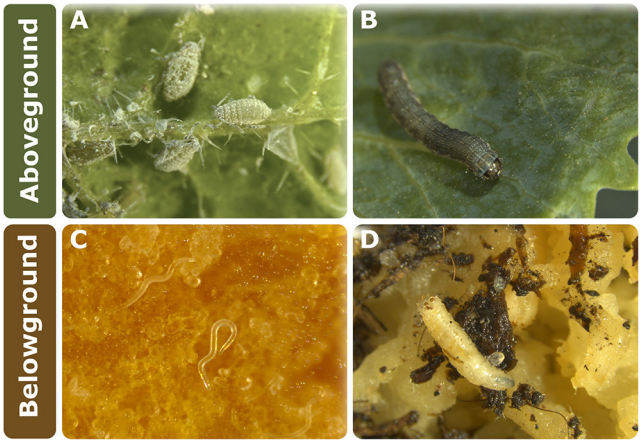

Figure 1

Examples of aboveground and belowground herbivores. **(A)** Cabbage aphids, **(B)** the caterpillar of the beet armyworm, **(C)** a plant-eating nematode, and **(D)** the larvae of the cabbage root fly. (Photo credits: Axel Touw).

PLANTS: SURVIVING IN A DANGEROUS WORLD

Plants are an important food source for many creatures, including humans. Plant eaters, or **herbivores**, can be large mammals like cows, sheep, or horses, but most of them are actually much tinier, such as caterpillars or aphids (Figure 1). Because these tiny herbivores usually occur in large numbers, they can cause a lot of damage. Insects, for example, are the most diverse group of animals on Earth. There are around 1 million known species of insects, of which about half are herbivores. In comparison, there are only around 5,500 mammal species living on Earth. In addition to the large and small herbivores aboveground, there are many plant feeders living belowground as well. The soil is filled with many kinds of herbivores that feed on plant roots, including insect larvae, tiny worms called **nematodes**, and spider-like creatures called mites (Figure 1).

HERBIVORE

An animal that eats plants.

NEMATODES

Tiny, wormlike animals that mostly occur in the soil, but also in seas or lakes, in the intestines of animals, and even in the guts of insects.

There are usually high numbers of herbivores present in the soil, just like there are aboveground. For example, there are 30,000 known nematodes species, of which around 10% are plant eaters. One single female nematode produces up to 200 eggs. This means that a single plant can be attacked by thousands of nematodes at the same time. Chewing insects are another danger. They may chew through the water transport system of plant roots, which can cause the leaves to droop and the plant to die from lack of water.

HOW DO PLANTS DEFEND THEMSELVES?

With so many creatures trying to attack them, you can imagine that plants have a hard time surviving. Since plants cannot flee from their attackers, they had to evolve ways of defending themselves. Plants have developed several defenses against herbivores [1]. Some **plant defenses** are easy to see, like the thorns of a rose, the hairs on the leaf of a stinging nettle, or the thick skin of beetroots. Other defenses,

PLANT DEFENSES

Features of a plant that affect the behavior, growth, or survival of herbivores.

such as chemical defenses, are less visible. Each plant produces thousands of different chemicals, all involved in essential processes. Some chemicals, like sugars, provide energy to the plant. Other groups of chemicals help to defend plants against attackers. These chemical defenses can make the plant taste bad, which prevents herbivores from eating plant tissues. In some cases, the chemicals can even be toxic. Chemical defenses can affect humans too. There are many plants that would make you feel very sick if you ate them, for example the berries of black nightshade. Some plants, such as poison ivy or hogweed, can give you a rash and even cause burns when you touch them. Most chemical defenses are not that bad, though. In fact, chances are high that you have been exposed to plant chemical defenses yourself.

We have grown to like the taste of some chemicals that plants produce. Have you ever put mustard on your hotdog or sausage, or enjoyed a nice Indian curry with mustard seeds? The sharp-bitter taste of mustard is caused by defense chemicals called **glucosinolates**. In the wild, glucosinolates help plants to defend themselves against insects, fungi, and bacteria. The caffeine in coffee, which helps people to wake up in the morning, is not made by coffee trees to please humans. In reality, coffee trees produce caffeine to protect their seeds—the coffee beans—from insect attacks. Caffeine not only gives coffee beans their bitter taste, but it can also paralyze or kill insects trying to feed on them.

GLUCOSINOLATES

Defense substances responsible for the sharp bitter taste of mustard and wasabi. Although most humans enjoy their taste, they are toxic to most insects, nematodes and bacteria.

These examples illustrate that chemical defenses are an effective way for plants to protect themselves against herbivores in their environments. Nevertheless, most plants are not completely defended by these chemicals. If you take a good look at the plants around you, you will notice that most plants show some damage, such as holes in their leaves. This is because the production of chemical defenses comes at a cost. Plants do not only have to worry about defending themselves, but they must also put energy into growth, producing flowers, and making seeds. So, the energy plants can spend on producing defenses is limited. Plants must make use of this limited amount of energy in an efficient way.

HOW DO PLANTS DEFEND THEMSELVES EFFICIENTLY?

Fossils of herbivore-damaged leaves show that plants and herbivores have been living together on Earth for more than 400 million years. During this time, plants have developed several ways to produce defenses in a cost-efficient manner. One way is to produce defenses only when necessary, for example, when insects start eating them [2]. By only producing defenses when under attack, plants save energy when no dangers are present. The disadvantage of this strategy is that defense production will only begin after the herbivore starts eating. Because defense production takes time, the plant can suffer significant damage before the herbivore leaves or dies.

Another strategy is to always have some defenses at hand but in limited amounts. In this case, the plant moves most defenses to the plant parts that are most important for survival and are vulnerable to attack by herbivores [3]. This would be like defending a castle by putting the soldiers on the outer wall, where the first attack would occur and where the castle is most vulnerable. Clearly, the treasure in the castle would be well guarded too, as this is the most valuable. Aboveground, such valuable plant parts include young leaves, flowers, and seeds, which play essential roles in energy production or in producing the next generation.

Belowground, various parts of the root system also have different values. The root systems of plants like tomato or cabbage consist of three parts: the **taproot**, lateral roots, and fine roots (Figure 2). Lateral and fine roots help the plant take up valuable nutrients and water from the soil. The taproot is the main root that collects all the water and nutrients absorbed by the lateral and fine roots and distributes them to the aboveground parts. Simultaneously, sugars and other substances produced in the leaves move through the taproot in the other direction. The important role of the taproot in transport of nutrients and water makes it an essential part of the root system. When herbivores damage the taproot, the essential transport routes are broken, and the plant will die. In plants like beets, the taproot stores energy in the form of sugar. This is like the treasure in the castle. The taproot is therefore considered the most valuable root part and is defended the most, followed by the lateral and fine roots [4] (Figure 2).

TAPROOT

Main root from which lateral roots arise. Collects water and nutrients from the rest of the root system and distributes them aboveground. In carrots and beetroots, it stores starch and nutrients.

HOW DO PLANT DEFENSES AFFECT SOIL HERBIVORES?

Herbivores decide which root part to eat based both on its nutritional value and on how well it is defended [5]. Most herbivores would prefer to feed on the taproot since it is the most nutritious part of the root system. However, as mentioned earlier, the taproot is also the best-defended part. Not all herbivores can overcome these chemical defenses. Some herbivores, like the larvae of the cabbage root fly, can deactivate chemical defenses and feed on the taproot [4]. Other herbivores, like the larvae of the European June beetle, cannot deal with the high defense levels in the taproot and instead eat the lateral and fine roots (Figure 2). The distribution of chemical defenses across the root system and the ability of herbivores to overcome these defenses can therefore have a strong influence on where herbivores can be found in the soil.

HOW CAN SCIENTISTS USE THIS KNOWLEDGE?

The knowledge gained by studying the defense systems of plants helps us to understand how plants interact with herbivores and other

Figure 2

The distribution of chemical defenses over a root system, and how this affects belowground herbivores. Red indicates the highest defense level in the root system and yellow indicates the lowest level. Chemical defenses are generally highest in the taproot (red), followed by the lateral roots (orange) and the fine roots (yellow). Some insect herbivores, like the cabbage root fly, can deactivate a plant's chemical defenses and can eat the taproot where defenses are highest. Other herbivores, like the European June beetle, cannot deactivate plant defenses and therefore they eat the fine roots, where chemical defense levels are lower. (Image credit: Jennifer Gabriel).

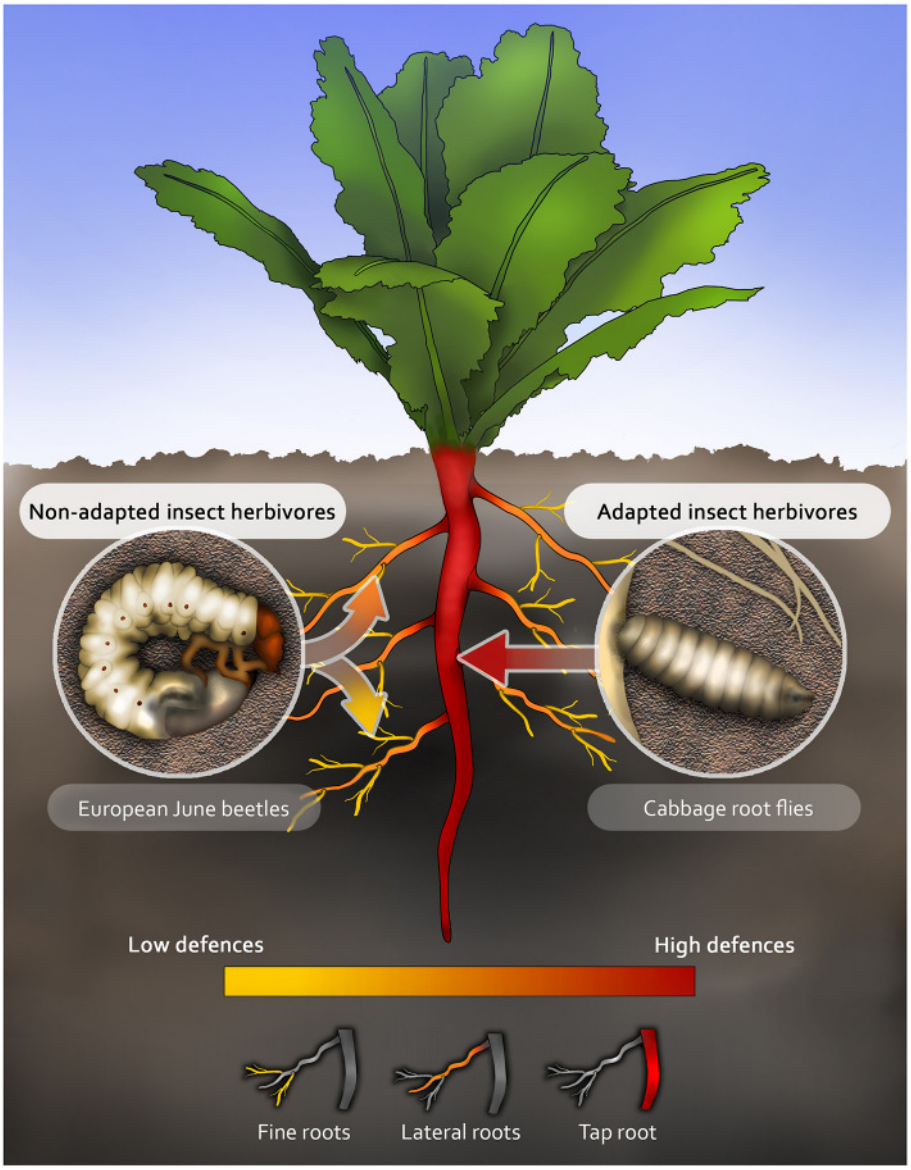

Figure 2

animals in their environments. In addition, knowing how plants defend themselves can help us to develop more environmentally friendly ways of growing crops. **Plant breeding** can create new crop varieties, such as plants with nicer colors, more interesting tastes, or bigger fruits. Similarly, plant breeders can create crops that are better defended against attackers. To do so, plant breeders must understand how plants produce defenses, and which attackers those defenses are effective against. Scientists who study plant defenses using lab experiments and field studies collect this kind of information. By creating crops with better defenses, we can help farmers to reduce the amounts of chemical pesticides they use. This is good news for both human health and the health of our environment.

PLANT BREEDING

The science of creating new plant varieties with desirable characteristics like taste, smell, color, or resistance to herbivores or certain environmental conditions like drought.

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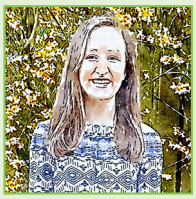
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

AVANI, AGE: 10

Hello, I am Avani. I enjoy running and swimming. I am also a dancer. I love going on walks with my dog, or collecting stones. I love math, science and I love sports. I enjoy playing video games, and calling friends. I love nature and cold windy weather.



CATHERINE, AGE: 15

I love music and singing, I play the violin and guitar and I also enjoy writing! I am part of a highland dance troup and volunteer with children at local kids clubs and guides. I enjoy attending youth events at my church and doing fitness. I hope that by reviewing these articles I could learn about new and interesting stuff!

HARRISON, AGE: 11

I love playing sports such as hockey and go running and chasing my dog! I also love discovering new things, but not new food! Because I currently go to primary school I am excited to start my new secondary school and try lots of new subjects. My favorite subject at the minute is maths.

AUTHORS

AXEL J. TOUW

Axel has been fascinated by nature since he was young. At that time, he was mostly interested in dinosaurs, cats, dogs, lizards, and frogs, but particularly in birds. Actually, the first thing he ever drew was an owl (with some imagination). While studying biology, he became interested in how plants communicate, especially with insects. Today, Axel studies how plants defend themselves against microbes, nematodes, and insects. In his free time, he likes to be outside, play football, read, and cook. He also tries to use the knowledge gained during his research in his garden, with varying degrees of success. *axel.touw@idiv.de

NICOLE M. VAN DAM

Nicole was born and grew up in the Netherlands with her parents and two younger sisters. As a kid, she liked to experiment with insects. For example, she tested whether ants can swim by putting them in puddles (in case you are wondering, they do quite well). She studied biology in Wageningen, the Netherlands. There she became interested in how plants can defend themselves and how farmers can use this knowledge to reduce pesticide use. After doing a lot more experiments with insects and plants in various places in the world, she became a professor. In her free time, she likes to do yoga and to watch movies with her two sons (19 and 21). Together with her husband, she likes to grow organic fruits and vegetables in her garden. There she also finds inspiration for new research projects.