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INSPIRED BY NATURE: FIGHTING PESTS WITH FRIENDLY BACTERIA

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YOUNG REVIEWERS:

ANNA
AGE: 15

JOCELYN
AGE: 15

MAYTE
AGE: 9

The starting point of this story is an imaginary garden. Within this garden we find plants, insects, and *Bacillus thuringiensis*, a friendly type of bacteria that helps humans in the fight against different pests. These bacteria are quite successful in nature, partly due to their ability to go into "sleep mode" when the conditions are not good for them, and their production of powerful weapons that help them survive. This article will tell you about these fascinating features, and we will explain how humans can use the weapons of these bacteria for environmentally friendly crop-protection strategies. Some of *B. thuringiensis*'s weapons may also help in the fight against certain dangerous parasites that infect humans and animals. Investigations of bacteria and their weapons can inspire us to find novel solutions for current challenges in agriculture and health.

A BATTLE IN FRONT OF US

Imagine a beautiful sunny day in a green garden. Plants are ready to be harvested and turned into tasty meals. You see some playful insects moving around as you lay on the ground. It looks peaceful for us, but a detailed look would reveal an intense battle happening right in front our eyes ... it just takes place on a tiny scale that we cannot see.

Each organism, from the plants you see to the tiny microorganisms in the soil, is fighting for survival. Some make strategic collaborations, some build strong defense mechanisms, others boost their attack tactics. Everybody is constantly developing a game plan to stay alive. Scientists around the world study these players and their strategies, not only to understand them, but also to inspire new solutions for human challenges.

BACILLUS THURINGIENSIS, SMALL BUT POWERFUL

One fascinating player is the bacterium *Bacillus thuringiensis*, commonly known as Bt. Bt can only be seen with a microscope, but its impressive features make it powerful enough to affect areas such as agriculture and health. It has been more than a century since the official discovery of Bt and its beneficial applications, however, some texts suggest that gardeners in ancient Egypt already used bacteria -likely Bt- to protect gardens around pharaohs' houses and tombs [1].

Bt is found almost everywhere, including in our imaginary garden. It is a very adaptable organism, so you can find it in the soil, associated with plants, in water, and even inside dead insects. To survive in diverse and challenging environments, Bt uses a special strategy: it produces **spores**.

SPORE

Microscopic particles made of cells that are in "sleep mode", covered with protective layers. Spores are produced by some microorganisms to resist harsh conditions.

When Life is Rough, Make Spores

When it rains, you put on a raincoat; when it is sunny, you apply sunscreen; and when it is cold, you wear more layers—all to protect yourself from external factors. Well, a spore is protection taken to the limit. When the surroundings are not good for Bt, it shields itself in protective layers and goes into "sleep-mode" (Figure 1). This dormant capsule is called a spore. In the spore state, all life functions are reduced to a minimum until the environment is favorable again. Spores are very difficult to destroy and extremely durable. In the spore state, Bt can endure extreme temperatures, drought, lack of nutrients, and even some disinfectants. *Bacillus pumilus*, a member of another *Bacillus* species, produces spores so resistant that they even survive in space [2]!

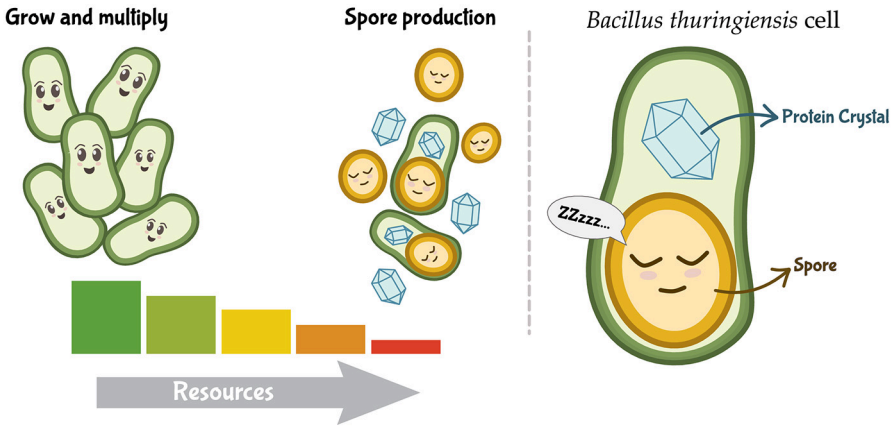

Figure 1

In favorable environments, Bt grows and multiplies. But when resources are limited and conditions are hard for living, Bt sets up a "sleep mode" covered by protective layers: the spore. During spore production, Bt also produces crystals made of proteins.

Crystals, a Secret Weapon to Help Spores

When Bt makes spores, it makes more than protective layers—it also produces crystals. These crystals are made of proteins and look like very tiny sugar granules (Figure 1). They are one of Bt's finest weapons in the fight for survival. The crystals ensure that the spore "wakes up" in a favorable environment rich in nutrients, so that Bt can restart normal functions and thrive.

This strategy has four steps (Figure 2). Picture some Bt spores and crystals, smaller than dust particles, settling on a plant's leaf in your imaginary garden. In the first step, an insect feeds on the leaf, which is "seasoned" with spores and crystals. Then, inside the insect's gut, the crystals are activated. Inactive crystals are like keys that are folded in half, once unfolded, they become active and can connect with

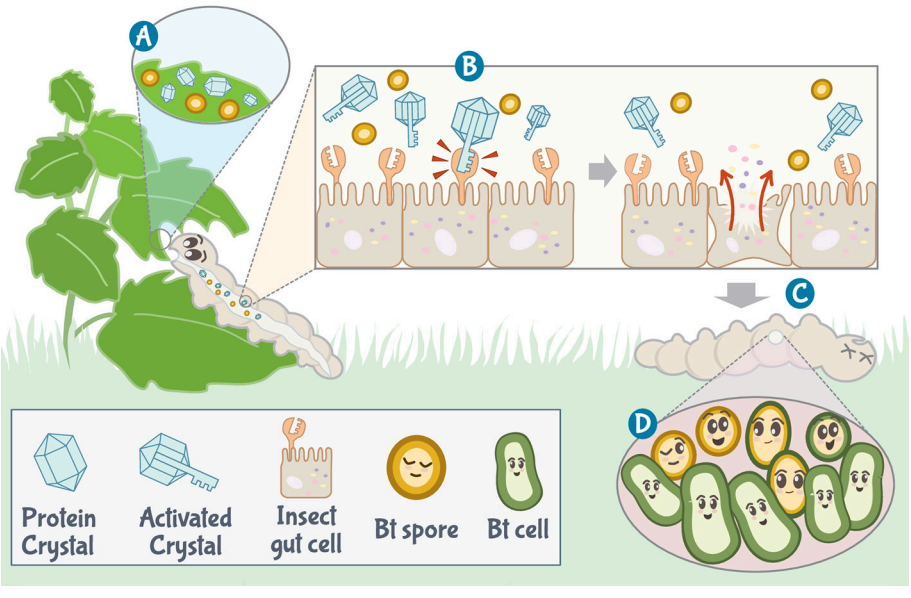

Figure 2

Bacillus thuringiensis (Bt) survival strategy. **(A)** An insect ingests Bt spores and crystals. **(B, C)** Inside the insect, the protein crystals are activated and damage the insect's gut cells, which eventually kills the insect. **(D)** In this nutrient-rich environment, Bt spores "wake up", grow, and multiply.

the insect's gut cells, by doing so they open "doors" into the cells. In the third step, the insect dies after too many crystal keys open too many "doors" into the gut's cells. The insect's death is good news for the plant! Finally, the Bt spores "wake up" in a nutrient-rich and safe environment, inside the dead insect. Bt uses the nutrients released from the insect cells to grow and multiply (Figure 2).

BT: AN ALLY AGAINST INSECT PESTS

So, researchers discovered that Bt is an ally for plants and an enemy for the insects that feed on those plants. Humans also have insect enemies, for example pests that eat our crops, or mosquitoes that transmit diseases. Scientists wondered if Bt could be an ally for humans too, and from that question a great partnership was born. Today, Bt is famous worldwide because it helps farmers to fight against **agricultural pests** [1, 3]. The pest-killing crystal proteins are so important that more than a thousand different ones have been identified. The Bacterial Pesticidal Protein Resource Center (BPPRC) gathers information on these proteins and the organisms that produce them [4].

AGRICULTURAL PESTS

Organisms, for example certain insects, nematodes, and fungi; that damage or destroy crops. They make it hard for farmers to grow enough food, leading to low crop yields.

Before we continue, it is necessary to clarify a detail. So far, we described the Bt by some general features, but not every Bt is exactly the same. In fact, there are many subtypes of Bt, which are all related but not identical. Think about how we have very different kinds of dogs, even though the scientific name for all dogs is *Canis familiaris*.

A single Bt cannot produce all types of pest-killing proteins, rather each type of Bt specializes in making a subset of those proteins effective against a particular target. So, how do we know which Bt can be helpful for us? One way to match specific Bts with their insect targets is by studying Bts collected from dead insects and from the surroundings of the plants we want to protect.

For example, Bt kurstaki was found inside a moth and, after investigation, it was discovered that Bt kurstaki is a powerful ally against the diamondback moth. This moth is the most destructive pest of crops like broccoli, cauliflower, and cabbage. And from grain dust samples collected by farmers, we found a Bt champion against the corn root worm. The worm is actually the larvae of a beetle, and it is very damaging for plant roots.

Bt pest-killing proteins are highly specific, just as every key can open only a specific door. Humans, other animals, and beneficial insects are not the targets of Bt's strategy. That is why Bt is safe to use, especially in plants that become our food. In contrast, synthetic pesticides are not so specific, so they are toxic for good and bad organisms, even for humans.

BT ALSO KILLS PARASITES

NEMATODES

Tiny animals that look like worms, some benefit ecosystems; while others harm plants, animals, or humans.

PARASITIC

Describes an organism (a parasite) that lives at the expense of another organism, harming it in the process.

Bt not only kills insect pests, it can also be toxic for **nematodes**, a type of small roundworm (learn more about nematodes in these Young Minds here and here). Some nematodes live and feed in the soil, where they are an accessible target for Bt. However, other nematodes are dangerous, because they are **parasitic** and prefer to live inside animals like pigs, horses, and humans, where they cause terrible diseases.

Parasitic nematodes have similarities to the ones that live in soil. Therefore, researchers had the idea to use Bt crystals that work on soil nematodes to fight against the disease-causing ones [3, 5]. Some nematodes are no longer destroyed by current medical treatments, which is why novel therapies, like Bt crystals, are urgently needed.

Research is still ongoing, but there is evidence that Bt kills nematodes that infect hamsters, pigs, dogs, sheep, and goats. This suggests that, with more studies, we could create a safe and effective Bt-based treatment that would help people who suffer from diseases caused by nematode infections.

FUTURE CHALLENGES AND OPPORTUNITIES: BECAUSE NATURE FIGHTS BACK

Organisms in nature change, evolve, and adjust their survival strategies. The pests that we target with the help of Bt are no exception. For example, changes in insects' cells can prevent or reduce the connection with Bt crystal proteins. That means that an insect (or a nematode) could eventually change so that it could face Bt without being harmed.

RESISTANT

An organism that develops a defense to withstand or fight off a harmful factor, for example a Bt crystal, is called resistant against that factor.

Resistant pests are a problem. Luckily for us, further research showed that Bt is equipped with a full arsenal of tools against its targets. Besides the crystals, Bt produces other powerful proteins [3]. We can study how to combine Bt's weapons to increase their effect and avoid resistance in targeted pests.

When a survival strategy is as successful as the one used by Bt, it is not a surprise to discover other organisms copying that tactic. For example, certain bacteria are also able to produce pest-killing proteins [4]. So, scientists keep searching for more potential allies in the fight against pests and parasites.

There are many nature-based solutions for current day challenges, sometimes we just need to imagine a garden and have a closer look.

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YOUNG REVIEWERS

ANNA, AGE: 15

Anna is an extremely bright student who has a keen interest in nature. With her natural curiosity and critical thinking ability she will be a fine scientist one day.

JOCELYN, AGE: 15

I am from Mexico and I like animals and plants and go out to discover new traditions and cultures. My favorite subjects at school are chemistry and mathematics.

MAYTE, AGE: 9

I like cooking, playing with bugs in the garden and my favorite subject is math. I also like shopping and hanging out with my friends.

AUTHORS

STEFANI DÍAZ-VALERIO

I grew up surrounded by the incredible biological diversity of Costa Rica. This inspired me to become a biologist. I moved to Germany to continue my studies, and I am now focused on microorganisms and their applications to improve our lives. I am particularly fascinated by *Bacillus* bacteria and the analysis of their genetic information. Science communication is another passion of mine. When I am not at the laboratory, I love to paint and to cook new dishes, especially desserts! *sdiazva@gwdg.de

HEIKO LIESEGANG

I grew up on the coast in northern Germany, and I am deeply fascinated by the diversity and beauty of life. I became a biologist to learn how living organisms formed this remarkably interdependent network that covers the whole planet. I study the genes of *Bacillus* bacteria to develop strains for biotechnology that help the industry to become sustainable and environmentally friendly. My vision is a world that gains wealth from renewable biological resources without producing any waste. I love to share my fascination with science with people outside the scientific world, especially those who are still in school.