Don’t Prey on Me: How Bacteria Avoid Predators

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April 2021

Imagine you’re being chased by something that wants to kill you. It’s much bigger than you – how do you protect yourself? Maybe you attempt to outrun it. Maybe you put on a disguise so it can’t recognize you. Maybe you find a way to fight back. Believe it or not, these are all ways that bacteria protect themselves from natural predators. Over many generations, bacteria have evolved these mechanisms – and more – to avoid being consumed. For such small organisms, bacteria have found complex ways to survive dangerous environments.

We’re All in This Together

In the ocean, bacteria may be hunted by single-cell golden algae, including *Ochromonas* species, and other predators. In order to avoid these predators, some bacterial species, including members of the genus *Flectobacillus*, make themselves harder to consume. These species are able to form filaments – nearby bacteria aggregate into long, thin chains which may be larger than what predators can ingest (see figure 1). *Flectobacillus* species seem to primarily form these filaments when in the proximity of predators (see figure 2), so a research team led by Dr. Martin Hahn (1998) explored the factors which cause bacteria to group together into chains. They found that the presence of predators indirectly encouraged filament formation. As bacteria were hunted and killed, the population’s reduced size induced a faster growth rate in the surviving bacteria which led to the development of filaments. The ability of *Flectobacillus* species to form long, thin chains of bacteria therefore seems to be, at least in part, an adaption to predators which protects them and enables the total population to survive longer when being hunted.

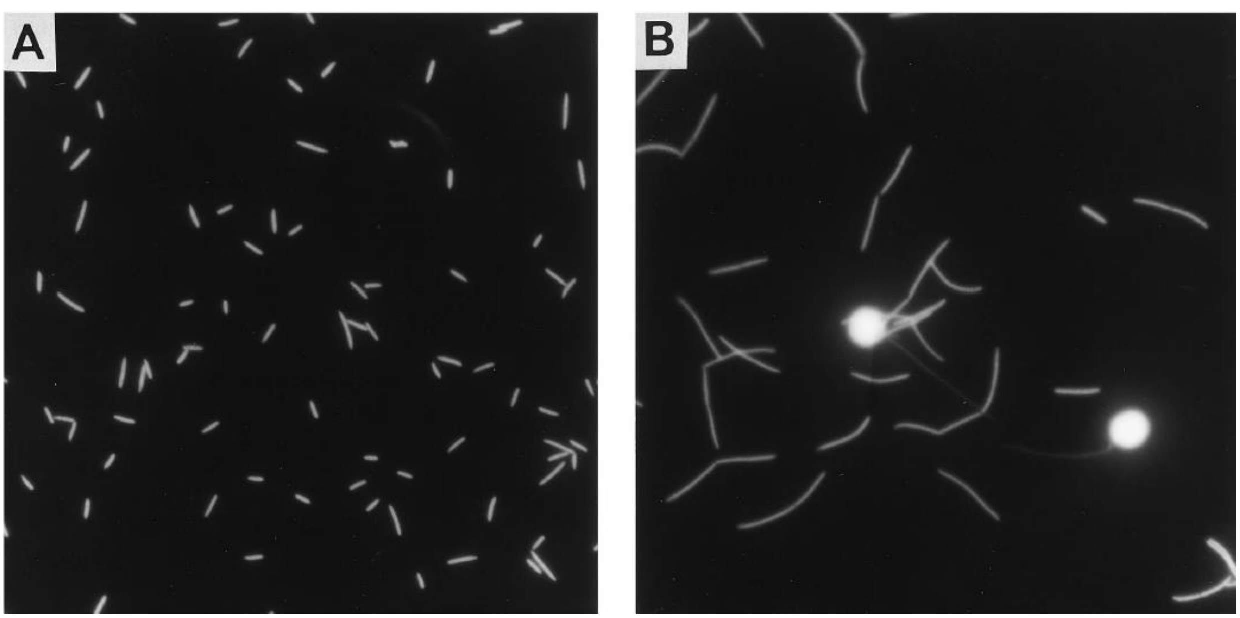

Figure 1 Photomicrographs of a *Flectobacillus* species grown without predation (A) and after introduction of a grazing predator, the golden algae *Ochromonas*. (B). Source: Hahn et al., 1999

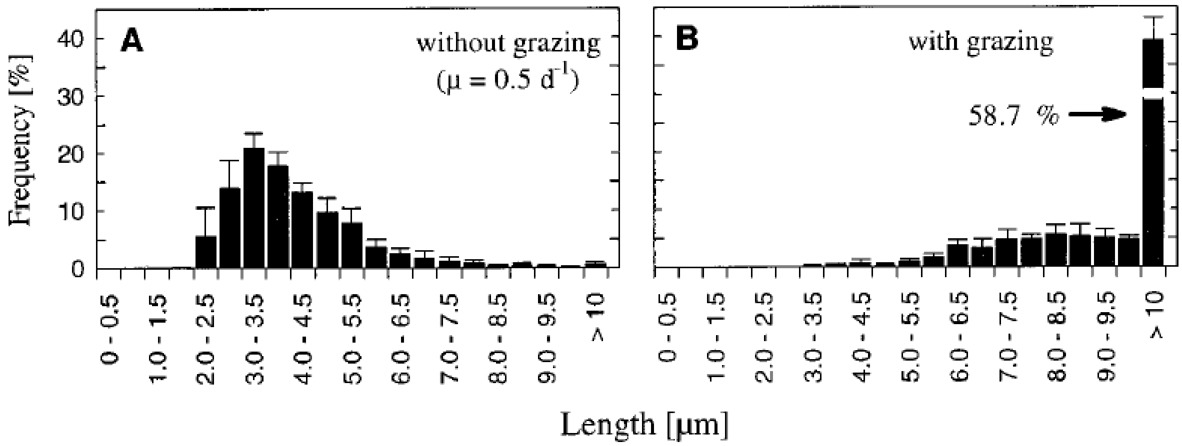

Figure 2 Cell size distributions of a *Flectobacillus* species grown without (A) and with predation by the golden algae *Ochromonas* (B). Source: Hahn et al., 1999

Run, Forrest, Run

Over many generations, zebra evolved faster running speeds so that they could avoid being caught and eaten by lions. Similarly, many bacterial species appear to have evolved faster swimming speeds in order to outrun predators, such as golden algae and protists. In 2005, Dr. Carsten Matz and Dr. Klaus Jürgens tested the amount of predation on multiple strains of bacteria from the genus Pseudomonas. They found that as a strain's swimming speed increased, the rate at which it was consumed by predators decreased. They proposed that higher swimming speeds likely evolved as a mechanism of avoiding predators, since the energy needed to swim so quickly would otherwise be costly to the bacteria, negatively impacting survival.

Not the Droids You're Looking For

Bacterial predators must recognize their prey before deciding to ingest them. They do so by inspecting the receptor proteins on the outside of the bacterial cell wall, which convey the identity of the bacterium. If a bacterium has a mutation in its receptor proteins so that they look different from the rest of the population, it might not be recognized by predators. Over time, these mutations could lead to the development of new strains of bacteria that differ in their receptor proteins since individuals with mutated receptors survive longer from predators. Research by Dr. Hans Wildschutte and his colleagues (2004) suggests this may be the case in Salmonella enterica, each strain of which presents only a few of the over 70 different classified O-antigens, a type of receptor protein specific to Salmonella (and some other bacterial species). As expected, predators fed on each strain at a rate dependent on the specific O-antigens present on the outside of the cell. Since certain strains were able to avoid identification by predators, the total population of Salmonella enterica, including all strains, should be able to survive most predators, making variation in the O-antigen beneficial.

Everybody Was Kung Fu Fighting

Though the previously discussed mechanisms have been defensive, some bacterial species go on the offensive and release toxins that are harmful to potential predators. These chemicals are often produced during metabolism, the process of creating energy from sunlight or other nutrients. They are not able to be used by the bacterium (but also do not harm it) so they are released into the environment, where they could kill predators before they are able to hunt the bacteria. Since metabolism is generally inefficient, producing useless byproducts, there could be an advantage of these byproducts being toxic chemicals for the sake of protection from predators. Metabolism then serves a dual purpose and ensures greater survival for bacteria that produce toxins.

For instance, Dr. Qingling He and his colleagues (2016) found that Pseudomonas fluorescens and *Pseudomonas aurantiaca* are able to protect themselves from roundworms (Caenorhabditis elegans) through the production and release of toxic chemicals that kill these predators. In fact, *P. aurantiaca* killed over 25% of the roundworms present in a test of the toxicity of these bacteria! Although Dr. He and his colleagues could not determine the toxic compound released by *P. aurantiaca*, they were able to identify that P. fluorescens releases hydrogen cyanide, a known toxin, to kill roundworms in the environment. Even though there is more to learn about bacteria and their toxic byproducts of metabolism, it is clear that releasing toxins can enable bacteria to survive significantly longer than if they did not produce such compounds.

Interestingly, bacteria seem to modulate how much of these toxic products they make depending on the presence (and amount) of predators in the area. A research team led by Dr. Alexandre Jousset (2010) looked into the way P. fluorescens protects itself from amoebas, a common bacterial predator. They found that the bacteria produce at least four different toxins to fight off amoebas, three of which were produced in greater quantities when the bacteria were exposed to chemical compounds produced by predators. They argue that these toxins are probably to some extent predator-specific, since the toxins which saw the greatest increase in quantity after exposure to chemicals from amoebas were those that were most harmful to these predators. However, toxin release decreased by up to 50% after the bacteria came under direct contact with amoebas, suggesting that amoebas may be able to suppress bacterial toxin production. This shows that bacteria and their predators have co-evolved ways to fight and neutralize each other, like a multi-generational episode of Tom and Jerry.

Mysterious As the Dark Side of the Moon

There is one structure that some bacteria have, the function of which has baffled microbiologists for decades. This structure, a protein layer around the outside of bacterial cells (particularly those in the genus *Synechococcus*), called the S layer, has been implicated in anti-predation strategies, although the exact mechanism through which it protects bacteria is still being determined. Historically, the S layer was thought to serve as a barrier or shield of sorts, physically defending the bacteria from predators’ attempts to engulf them. However, a research team led by Dr. Suzanne Strom (2017) found a surprising relationship between the S layer and vulnerability to predators. They created mutant bacteria that were deficient for the SwmA protein, which makes up the S layer, and compared the rates at which these mutants were preyed on in comparison to wild-type bacteria with intact SwmA proteins. They found that the mutant bacteria without the S layer were able to survive more than the wild-type bacteria – meaning the S layer actually made bacteria more vulnerable to predation! Dr. Strom and her colleagues argue that the S layer enables predators to attach to bacteria easier and in that way makes these bacteria more likely to be eaten than others that are deficient in the S layer.

This is puzzling. Why would bacteria develop a structure that puts them more at risk for being eaten by predators? The answer, it seems, comes from a 2005 study by Dr. Carsten Matz and Dr. Staffan Kjelleberg. They assert that the S layer protects the bacteria after they are swallowed by the predator, rather than preventing the predator from eating them in the first place. Some species of *Synechococcus* have been found to be released from the predator's body within minutes of being ingested, even though bacteria without an S layer continue to be digested. Their S layers are said to provide these bacteria with 'digestional resistance'; like Jonah escaping from the belly of the whale that swallowed him, the bacteria are able to be expelled from their predators unscathed. Being ingested does not lead to any harm to the bacteria. Therefore, the S layer serves as a unique yet effective strategy for surviving predators.

Bacteria have developed a variety of ways to avoid predation. These surprisingly complex behaviors and adaptations arose via evolution, which reinforces responses to environmental stresses that increase survival and reproduction. All these bacteria faced similar pressures from the environment – predators – but developed different ways to improve survival. In essence, evolution tells us that if there's more than one way to fix a problem, it's alright to get creative!

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