Carnivorous plants: No escape for mosquitoes

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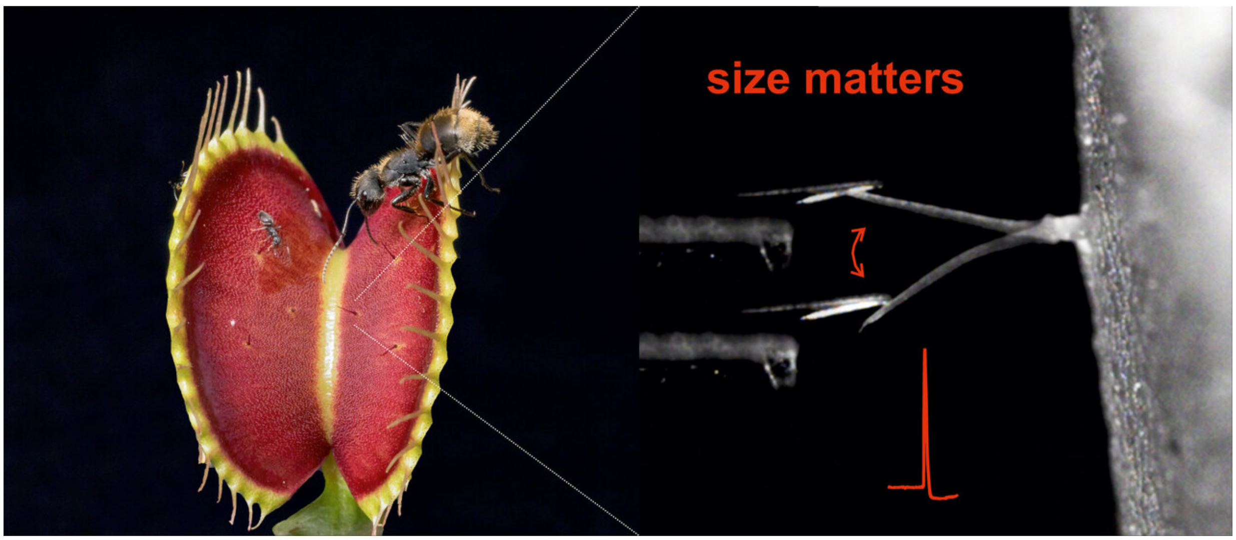

The Venus flytrap recognizes the size of its prey. Insects that are too small (left) are not able to apply the necessary force to stimulate the plant's tactile hairs (right) and thus trigger the trapping mechanism. Credit: Sönke Scherzer / University of Würzburg

Physically bound to a specific location, plants have to devise special ways to secure their supply of vital nutrients. Most plants have developed a root system to the nutrients they need in order to survive out of the soil. But what if nutrient-poor soils fail to provide the necessities of life? Carnivorous plants such as the Venus flytrap have found a way out of this dilemma.

The Venus flytrap is native to the wetlands of North and South Carolina on the East Coast of the U.S.. Instead of taking in nutrients through its roots alone, the carnivorous plant traps prey within its leaves that can snap shut within a fraction of a second. The plant is capable of sensing prey through delicate trigger hairs on the inside of its flat leaves. Since prey insects come in different sizes and the Venus flytrap cannot afford to be fussy, the plant grows traps across a variety of sizes.

Now, researchers from the universities of Würzburg and Cambridge have discovered that the tactile sensors in these traps already respond to minute pressure stimuli, converting them to electrical signals that cause the trap to close. They have published their results in the current issue of *Nature Plants*.

Trigger hair converts touch into electricity

"Each trap lobe features three to four multicellular hairs that are torsion-resistant except for a notch at the base. When an insect, lured by the smell, color or nectar of the trap, touches the trigger hair, the hair will yield in the area of the non-reinforced base. This causes the sensory cells in this area to be stretched on one side and compressed on the other side," says Professor Rainer Hedrich, explaining the operating principle of the Venus flytrap. The biophysicist and plant researcher, who holds the Chair of Botany I at the University of Würzburg, has been studying the carnivorous plant species for some time.

When the sensory cells are deformed in this way, the tactile sensors respond by converting mechanical energy into electrical signals, triggering an action potential, which rapidly propagates from the base of the trigger hair throughout the entire trap. When a trigger hair is touched a second time within a short time period, the process is restarted—and only then does the trap close.

But how much does an insect deflect the trigger hair? What is the minimum size and weight that an insect must have in order to be detected by the Venus flytrap? Professor Hedrich had these questions in mind when conducting his latest study. "It was clear from the beginning that we would not easily get the answers using flying insects," Professor Hedrich explains. So when looking for a suitable insect prey to use in their experiments, Professor Hedrich and his team opted for ants. Professor Walter Federle, a biomechanics expert and ant specialist at the University of Cambridge, provided the necessary expertise and support for the experiments of the Würzburg plant scientists.

Minimal deflection triggers electrical stimulation

How can ants be made to touch a trigger hair on command? To solve this problem, ant specialist Federle chose leaf-cutting ants. This ant species regularly commutes between the foraging site and the nest. For the experiment, Federle mounted single-trap lobes within the foraging trail of a leaf-cutting ant colony. He then monitored the ant traffic on the flytrap trail using a high-speed camera that recorded all contacts. The result: Federle's analysis yielded a minimum and maximum trigger hair deflection of 3.5 and 7.5 degrees, respectively.

Now in order to determine the angle and force necessary to trigger an action potential in the Venus flytrap, the scientists replaced the ants with computer-controlled micro-manipulators equipped with special force transducers. After the micro-manipulators had been deposited on the trigger hairs, the deflection angle was varied progressively. "We were surprised to find that our voltage detectors already recorded an action potential at a deflection of around 2.9 degrees," says Dr. Sönke Scherzer, lead author of the study and a scientist in Professor Hedrich's department. This means that the Venus flytrap already detects the weakest contact with a leaf-cutting ant.

A trap for each fly size

An ant or housefly creates a force when walking which is approximately equivalent to its body weight. So a fly weighing ten milligrams is capable of generating 100 micronewtons, a force that is easily sufficient to excite a large trap. However, if a mosquito weighing just three milligrams ends up in such a large trap, the trigger hairs will not be deflected.

But since a mosquito, too, can be an important source of nutrients, the Venus flytrap has also developed smaller traps during the course of evolution. These mini-traps also respond to the smaller forces generated by the lightweight mosquito. "This trap-size-based sensitivity of the trigger hairs is crucial for the economic efficiency of the traps," Professor Hedrich explains. After all, it costs the plant much more energy to reopen a large trap than a small one. "If underweight, low-nutrient prey insects were able to trigger large traps, the cost-benefit ratio would turn out negative and the Venus flytrap would slowly starve in the worst case," Professor Hedrich explains.

When trigger hairs get weary

Once the trap has closed, the insect prey usually does not just accept its fate. Instead it struggles and tries to escape. In its panic, it constantly touches the tactile hairs, triggering up to 100 action potentials in two hours. According to Professor Hedrich, the Venus flytrap takes into account these electrical signals and initiates a corresponding response that ranges from the production and excretion of digestive enzymes to taking up the nutrients from the decomposed prey.

The scientists conducted another experiment to determine how often a single trigger hair can be stimulated within one hour. The result: "From a frequency of a tenth of a hertz, that is one stimulation every ten seconds, the trigger hair starts to exhibit signs of fatigue," says Sönke Scherzer. At higher frequencies, an action potential was no longer triggered each time a tactile hair is stimulated and eventually the electrical events did not take place at all. When the scientists interrupted the repeated stimulation sequence for a minute, the hair fully regained its mechano-electrical properties.

Sensory cells under the microscope

To build on this research, the researchers aim to find out how the flytrap counts and why the tactile hair stops responding when stimulated at high frequency. For this purpose, they will isolate the trigger hairs and sensory cells and determine a number of properties such as the fatigue and recovery of the ion channels that convert the tactile stimulus to an electrical event.

More information: S. Scherzer et al, Venus flytrap trigger hairs are micronewton mechano-sensors that can detect small insect prey, *Nature Plants* (2019). DOI: 10.1038/s41477-019-0465-1

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