

Botanists are getting a whiff of the ways that plants smell one another. Some plants recognize injured neighbors by scent; others sniff out a meal

By Daniel Chamovitz

WHAT A PLANT SMELLS

CUSCUTA PENTAGONA IS NOT YOUR NORMAL PLANT. IT IS A SPINDLY ORANGE VINE THAT CAN GROW up to three feet high, produces tiny white flowers of five petals and is found all over North America. What is unique about *Cuscuta* [commonly known as dodder] is that it has no leaves. And it isn't green, because it lacks chlorophyll, the pigment that absorbs solar energy, allowing plants to turn light into sugars and oxygen through photosynthesis. *Cuscuta* gets its food from its neighbors. It is a parasitic plant. In order to live, *Cuscuta* attaches itself to a host plant and sucks off the nutrients provided by the host by burrowing an appendage into the plant's vascular system. What makes *Cuscuta* truly fascinating is that it has culinary preferences: it chooses which neighbors to attack.

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A *Cuscuta* seed germinates like any other plant seed. The new shoot grows into the air, and the new root burrows into the dirt. But a young dodder left on its own will die if it doesn't quickly find a host to live off of. As a dodder seedling grows, it moves its shoot tip in small circles, probing the surroundings the way we do with our hands when we are blindfolded or searching for the kitchen light in the middle of the night. While these movements seem random at first, if the dodder is next to another plant (say, a tomato), it's quickly obvious that it is bending and growing and rotating in the direction of the to-



FATAL FRAGRANCE

After smelling its way to a suitable host, a parasitic dodder vine wraps itself around a tomato plant, sucking out vital juices.

mato plant that will provide it with food. The dodder bends and grows and rotates until finally it finds a tomato leaf. But rather than touch the leaf, the dodder sinks down and keeps moving until it finds the *stem* of the tomato plant. In a final act of victory, it twirls itself around the stem, sends microprojections into the tomato's phloem (the vessels that carry the plant's sugary sap), and starts siphoning off sugars so that it can keep growing and eventually flower.

Consuelo De Moraes even documented this behavior on film. She is an entomologist at Pennsylvania State University whose main interest is understanding volatile chemical signaling between insects and plants and between plants themselves. One of her projects centered on figuring out how *Cuscuta* locates its prey. She demonstrated that the dodder vines never grow toward empty pots or pots with fake plants in them but faithfully grow toward tomato plants no matter where she put them—in the light, in the shade, wherever. De Moraes hypothesized that the dodder actually *smelled* the tomato. To check her hypothesis, she and her students put the dodder in a pot in a closed box and put the tomato in a second closed box. The two boxes were connected by a tube that entered the dodder's box on one side, thereby allowing the free flow of air between the boxes. The isolated dodder always grew toward the tube, suggesting that the tomato plant was giving off an odor that wafted through the tube into the dodder's box and that the dodder liked it.

If the *Cuscuta* was really going after the smell of the tomato, then perhaps De Moraes could just make a tomato perfume and see if the dodder would go for that. She created an *eau de tomato* stem extract that she placed on cotton swabs and then put the swabs on sticks in pots next to the *Cuscuta*. As a control, she put some of the solvents that she used to make the tomato perfume on other swabs of cotton and put these on sticks next to the *Cuscuta* as well. As predicted, she tricked the dodder into growing toward the cotton giving off the tomato smell, thinking it was going to find food, but not to the cotton with the solvents.

Given a choice between a tomato and some wheat, the dodder will choose the tomato. If you grow your dodder in a spot that is equidistant between two pots—one containing wheat, the other containing tomato—the dodder will go for the tomato.

At the basic chemical level, *eau de tomato* and *eau de wheat* are rather similar. Both contain beta-myrcene, a volatile compound (one of the hundreds of unique chemical smells known) that on its own can induce *Cuscuta* to grow toward it. So why the preference? One clear hypothesis is the complexity of the bouquet. In addition to beta-myrcene, the tomato gives off two other volatile chemicals that the dodder is attracted to, making for an overall irresistible dodder-attracting fragrance. Wheat, however, only contains one dodder-enticing odor, the beta-myrcene, and not the other two found in the tomato. What's more, wheat not

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only makes fewer attractants but also makes (Z)-3-Hexenyl acetate, which repels the dodder more than the beta-myrcene attracts it. In fact, the *Cuscuta* grows *away* from (Z)-3-Hexenyl acetate, finding the wheat simply repulsive.

(L)EAVESDROPPING

IN 1983 two teams of scientists published astonishing findings related to plant communication that revolutionized our understanding of everything from the willow tree to the lima bean. The scientists claimed that trees warn one another of an imminent leaf-eating-insect attack. News of their work soon spread to popular culture, with the idea of “talking trees” found in the pages not only of *Science* but of mainstream newspapers around the world.

David Rhoades and Gordon Orians, two scientists at the University of Washington, noticed that caterpillars were less likely to forage on leaves from willow trees if these trees were neighbors of other willows already infested with tent caterpillars. The healthy trees growing near the infested trees were resistant to the caterpillars because, as Rhoades discovered, the leaves of the resistant trees—but not of susceptible ones isolated from the infested trees—contained phenolic and tannin chemicals that made them unpalatable to the insects. Because the scientists could detect no physical connections between the damaged trees and their healthy neighbors—they did not share common roots, and their branches did not touch—Rhoades proposed that the attacked trees must be sending an airborne pheromonal message to the healthy trees. In other words, the infested trees signaled to the neighboring healthy trees, “Beware! Defend yourselves!”

Just three months later Dartmouth College researchers Ian Baldwin and Jack Schultz published a seminal paper that supported the Rhoades report. They studied poplar and sugar maple seedlings (about a foot tall) grown in airtight Plexiglas cages. They used two cages for their experiment. The first contained two populations of trees: 15 trees that had two leaves torn in half and 15 trees that were not damaged. The second cage contained the control trees, which of course were not damaged. Two days later the remaining leaves on the damaged trees contained increased levels of a number of chemicals that are known to inhibit the growth of caterpillars. The trees in the control cage did not show increases in any of these compounds. Baldwin and Schultz proposed that the damaged leaves, whether by tearing as in their experiments or by insect feeding as in Rhoades's observations of the willow trees, emitted a gaseous signal that enabled the damaged trees to communicate with the undamaged ones, which resulted in the latter defending themselves against imminent insect attack.

These early reports of plant signaling were often dismissed by other individuals in the scientific community as lacking the correct controls or as having correct results but exaggerated implica-

IN BRIEF

Plants release a bouquet of odors into the air around them. Biologists have confirmed that plants respond to one another's scents.

Some plants prepare for battle when they smell wounded neighbors, whereas the parasitic dodder vine sniffs out healthy hosts.

tions. But over the past decade the phenomenon of plant communication through smell has been shown again and again for a large number of plants, including barley, sagebrush and alder. While the phenomenon of plants being influenced by their neighbors through airborne chemical signals is now an accepted scientific paradigm, the question remains: Are plants truly communicating with one another (in other words, purposely warning of approaching danger), or are the healthy ones just eavesdropping on a soliloquy by the infested plants, not intended to be heard?

Martin Heil and his team at the Center for Research and Advanced Studies in Irapuato, Mexico, have been studying wild lima beans (*Phaseolus lunatus*) for the past several years to further explore this question. Heil knew that scientists had observed that when a lima bean plant is eaten by beetles, it responds in two ways. The leaves that are being eaten by the insects release a mixture of volatile chemicals into the air, and the flowers (though not directly attacked by the beetles) produce a nectar that attracts beetle-eating arthropods. Early in his career at the turn of the millennium, Heil had worked at the Max Planck Institute for Chemical Ecology in Jena, Germany, the same institute where Baldwin was (and still is) a director, and like Baldwin before him Heil wondered why it was that lima beans emitted these chemicals.

Heil and his colleagues placed lima bean plants that had been attacked by beetles next to plants that had been isolated from the beetles and monitored the air around different leaves. They chose a total of four leaves from three different plants: from a single plant that had been attacked with beetles they chose two leaves, one leaf that had been eaten and another that was not; a leaf from a neighboring but healthy “uninfested” plant; and a leaf from a plant that had been kept isolated from any contact with beetles or infested plants. They identified the volatile chemical in the air surrounding each leaf using an advanced technique known as gas chromatography/mass spectrometry (often featured on the show *CSI* and employed by perfume companies when they are developing a new fragrance).

Heil found that the air emitted from the foraged and the healthy leaves on the same plant contained essentially identical volatiles, whereas the air around the control leaf was clear of these gases. In addition, the air around the healthy leaves from the lima beans that neighbored beetle-infested plants also contained the same volatile chemicals as those detected from the foraged plants. The healthy plants were also less likely to be eaten by beetles.

But Heil was not convinced that damaged plants “talk” to other plants to warn them against impending attack. Rather he proposed that the neighboring plant must be practicing a form of olfactory eavesdropping on an internal signal actually intended for other leaves on the same plant.

Heil modified his experimental setup in a simple, albeit ingenious, way to test his hypothesis. He kept the two plants next to each other but enclosed the attacked leaves in plastic bags for 24 hours. When he checked the same four types of leaves as in the first experiment, the results were different. While the attacked leaf continued to emit the same chemical as it did before, the other leaves on the same vine and neighboring vines now resembled the control plant; the air around the leaves was clear.

Heil and his team opened the bag around the attacked leaf, and with the help of a small ventilator usually used on tiny mi-

crochips to help cool computers, they blew the air in one of two directions: either toward the neighboring leaves farther up the vine or away from the vine and into the open. They checked the gases coming out of the leaves higher up the stem and measured how much nectar they produced. The leaves blown with air coming from the attacked leaf started to emit the same gases themselves, and they also produced nectar. The leaves that were not exposed to the air from the attacked leaf remained the same.

The results were significant because they revealed that the gases emitted from an attacked leaf are necessary for the same plant to protect *its other leaves* from future attacks. In other words, when a leaf is attacked by an insect or by bacteria, it releases odors

that warn its brother leaves to protect themselves against imminent attack, similar to guard towers on the Great Wall of China lighting fires to warn of an oncoming assault.

The neighboring plant eavesdrops on a nearby olfactory conversation, which gives it essential information to help protect itself. In nature, this olfactory signal persists for at least a few feet (different volatile signals, depending on their chemical properties, travel for shorter or

much longer distances). For lima beans, which naturally enjoy crowding, this is more than enough to ensure that if one plant is in trouble, its neighbors will know about it.

Given a choice between a tomato and some wheat, the dodder will choose the tomato.

DO PLANTS SMELL?

PLANTS GIVE OFF a literal bouquet of smells. Imagine the fragrance of roses when you walk on a garden path in the summertime, or of freshly cut grass in the late spring, or of jasmine blooming at night. Without looking, we know when fruit is ready to eat, and no visitor to a botanical garden can be oblivious to the offensive odor of the world’s largest (and smelliest) flower, the *Amorphophallus titanum*, better known as the corpse flower. (Luckily, it blooms only once every few years.)

Many of these aromas are used in complex communication between plants and animals. The smells induce different pollinators to visit flowers and seed spreaders to visit fruits, and as author Michael Pollan points out, these aromas can even seduce people to spread flowers all over the world. But plants don’t just give off odors; as we have seen, they undoubtedly smell other plants.

Plants obviously don’t have olfactory nerves that connect to a brain that interprets the signals. But *Cuscuta*, Heil’s plants and other flora throughout our natural world respond to pheromones, just as we do. Plants detect a volatile chemical in the air, and they convert this signal (albeit nerve-free) into a physiological response. Surely this could be considered olfaction. ■

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