Plants host fungi on demand

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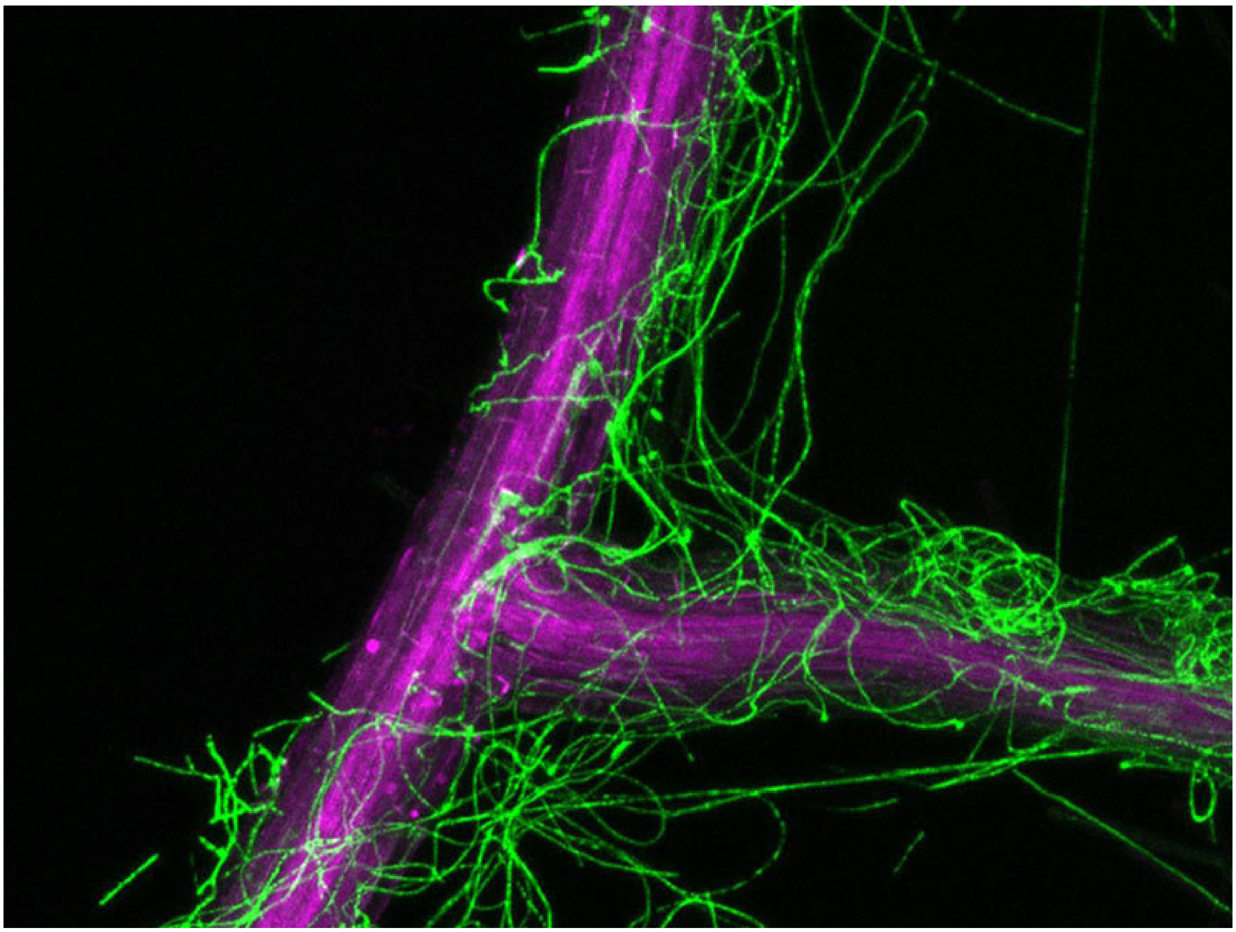

Fluorescent microscopy image of a root of Arabidopsis thaliana (violet) surrounded by a fungal mesh of Colletotrichum tofieldiae (green). The mesh also grows within the root cells (not shown). Credit: MPI f. Plant Breeding Research

For a long time, it was thought that the sole role of the immune system was to distinguish between friend and foe and to fend off pathogens. In fact, it is more like a microbial management system that is also involved in accommodating beneficial microorganisms in the plant when required. Researchers from the Max Planck Institute for Plant Breeding Research in Cologne in collaboration with an international consortium of other laboratories discovered this relationship between the model plant Arabidopsis thaliana, or thale cress, and the fungus Colletotrichum tofieldiae. The plant tolerates the fungus when it needs help in obtaining soluble phosphate from the soil and rejects the microbe if it can accomplish this task on its own.

Plants grow and thrive only if they have access to soluble phosphate in the soil. They are unable to utilize bound phosphate without help from other organisms. Most plants therefore maintain a mycorrhiza - a fungal mesh around their roots - that supplies them with vital soil-derived nutrients in exchange for carbohydrates, which they produce by photosynthesis.

Arabidopsis is one of the few plants that do not have a mycorrhiza. Instead, this species engages in a beneficial relationship with the soil fungus Colletotrichum tofieldiae. This fungus colonizes thale cress through its roots and then lives within and between the root cells. It converts insoluble phosphate in the soil into soluble phosphate and releases the nutrient via the fungal mesh to its plant host, which needs it for growth. "The beneficial interaction between thale cress and Colletotrichum came as a surprise to us, because this fungal family occurs almost everywhere as a pathogen," says Paul Schulze-Lefert, Director of the Max Planck Institute in Cologne. "In maize alone, a relative of this fungus causes crop losses that run into billions of dollars. We therefore wanted to know why Colletotrichum tofieldiae doesn't harm the thale cress plant."

Immune systems adapts to phosphate supplies

Because Schulze-Lefert and colleagues isolated the fungus from a thale cress plant in the Central Plateau of Spain and the fungus does not occur in thale cress plants growing in other regions, they suspected from the outset that the symbiotic relationship has something to do with the local environment. They noted that very little soluble phosphate is present in the soil in the Central Plateau. The Cologne-based scientists demonstrated that an intact innate immune system is needed for the symbiosis and allows the fungus to take up residence in the plant's roots only if the plant is not able to obtain enough soil phosphate on its own. However, if phosphate is plentiful, the plant launches a massive immune response. "It's a fantastically well-regulated system," Schulze-Lefert says. "A foe is therefore recognized as such only in specific circumstances. That's an entirely new take on the immune system."

The scientists were also able to show which processes are involved. One process is known as the "phosphate starvation response", by means of which the plant senses the availability of phosphate in the soil and relays this information to a circuit that accelerates or slows plant growth. If soluble phosphate becomes scarce, the nutrient sensing system communicates with one branch of the plant immune system to accommodate the fungal tenant inside roots. This branch of the immune system directs the synthesis of mustard oil glycosides. These compounds are responsible for the sharp and bitter taste of brassicas, which include thale cress, rapeseed, mustard and horseradish. Schulze-Lefert and his colleagues showed that in the absence of this synthesis pathway, C. tofieldiae becomes a life-threatening pathogen for thale cress.

"The thale cress plant controls its interaction with its tenant by linking its immune system to a sensor for phosphate availability," says Schulze-Lefert. "It's an elegant solution that extends the role of the immune system to ensure an external supply of nutrients under malnutrition conditions. This has not been previously observed in the plant kingdom."

Helper to one, pathogen to others

As a next step, the Max Planck researchers want to clarify which molecules mediate communication between the nutrient sensing and the immune systems and how this decision-making process is organized. The only species among the brassicas that do not synthesize mustard oil glycosides, namely the shepherd's purse, does not tolerate the fungus. For the shepherd's purse, C. tofieldiae is a deadly pathogen. Evidently, absence of the synthesis pathway for mustard oil glycosides means that the molecular basis for a beneficial coexistence is missing.

The findings are also remarkable in another sense. Whereas healthy plants are colonized by bacterial communities with a reproducible composition, there appears to be less selectivity in the choice of fungal tenants. It is almost as if the individual fungal species are present in the plants purely by accident, because there is no obvious pattern. "We've now shown that a Colletotrichum fungus which we discovered by accident does not take up residence in the plant by accident," says Schulze-Lefert. It serves the thale cress as a substitute for the missing mycorrhiza fungus. Without Colletotrichum, the plant would have a very poor chance of survival in low phosphate soils. The mutual coexistence is beneficial to both partners, but only as long as the right conditions prevail."

More information: Hiruma, K., Gerlach, N., Sacristán, S., Nakano, R. T., Hacquard, S., Kracher, B., Neumann, U., Ramírez, D., Bucher, M., O'Connell, R. and P. Schulze-Lefert. Root endophyte Colletotrichum tofieldiae confers plant fitness benefits that are phosphate status-dependent. *Cell*, 2016.

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