A few modifications in the genome turn a fungal plant pathogen into a potentially beneficial organism

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Because of their sedentary life, plants have to make the most of their surroundings. To do so, they take advantage of hitherto unknown molecular mechanisms to determine what benefits them and what harms them. They also grant microorganisms access to their roots in exchange for essential nutrients in the soil. The soil fungus *Colletotrichum tofieldiae* serves the model plant Arabidopsis as such a subtenant when required. The plant accepts the fungus as a phosphate supplier in situations where it has no access to those minerals itself, but rejects the fungus if it is able to tap phosphate supplies on its own. Thus, the plant very accurately weighs the demands of its environment to which it must respond. In the process, the plant's immune system plays a key role. Stéphane Hacquard, Paul Schulze-Lefert and Richard O'Connell of the Max Planck Institute for Plant Breeding Research in Cologne are addressing the question of what changes are responsible for ensuring that Colletotrichum tofieldiae no longer has to contend with the full brunt of the plant's immune system under certain conditions. They have found that just a few changes in the genome are sufficient to turn a pathogen into a partner.

Fungi of the genus Colletotrichum are usually pathogens. Colletotrichum tofieldiae must therefore have undergone changes in the course of evolution to make it a potential friend of Arabidopsis. "We wanted to know what molecular adaptations were needed in the fungus and in the plant to enable the two organisms to cooperate, with the plant acting as a host but maintaining control of the symbiotic relationship," says Stéphane Hacquard of the Cologne-based Max Planck Institute. "Our research therefore boils down to the question of how plants decide what benefits them and what harms them, and how they weigh the various options against each other," Hacquard adds.

To this end, the scientists compared the genomes of several strains of the beneficial species Colletotrichum tofieldiae collected on various continents with the genomes of its harmful cousin Colletotrichum incanum. They also investigated which genes the two fungi switch on when they gain access to a root, namely under conditions of sufficient and insufficient soluble phosphate in the soil.

The genetic comparison showed that the last common ancestor of the two species of fungi lived around eight million years ago and had a pathogenic lifestyle. The beneficial adaptations must therefore have occurred later in the evolutionary process. By drawing comparisons with other beneficial species of fungi, the scientists were also able to show that there are no universal genetic building blocks for the symbiotic coexistence of fungi and plants. "There is no standard set of genes that can ensure that a root fungus will be tolerated by its host plants," says Hacquard. "So this symbiotic relationship must have emerged several times independently in the course of evolution."

The Cologne-based scientists also showed that acceptance of the beneficial fungus is not associated with a radical change in its genome. The beneficial and pathogenic species have amazingly similar genomes. "The change from pathogen to beneficial lodger is therefore based on relatively few genetic changes," Hacquard says. "Of just under 13,000 genes, 11,300 are identical. During the eight million years since the two species diverged, the beneficial fungus has gained 1,009 genes and lost 198."

Particularly striking is the change in the number of effector genes. Effectors are proteins that enable microorganisms to suppress or switch off the immune system of plants. The beneficial fungus has only 133 effector genes, while its harmful relative has fifty percent more. Hacquard and his colleagues were also able to show that the effector genes of the beneficial fungus are hardly read during root colonization. Evidently, there is no need for the proteins they code for. Hence, the mutually beneficial cooperation makes do with almost no effector proteins.

The scientists in Cologne also discovered that the beneficial fungus either does not read the genes it has inherited through its pathogenic phylogeny or reads them very late. "We conclude that the symbiotic relationship is due to the fact that the genes originally responsible for the pathogenesis of the fungus remain switched off and do not come into play," Hacquard says.

The scientists have also looked at how Arabidopsis responds to the two fungi. They showed that the plant's response depends on the amount of soluble phosphate in the soil. If sufficient phosphate is available, the plant activates its immune system to bar the beneficial fungus from its roots because it does not need it. However, when faced with a growth-restricting lack of phosphate in the soil, it suppresses its immune response to the beneficial fungus. However, the harmful fungus is exposed to the full brunt of the plant's immune system under all conditions, because it has nothing to offer Arabidopsis.

In a nutrient-deficient environment, the plant's immune response is therefore only dampened when, in return, the beneficial fungus collects phosphate from the soil and supplies it to the root for plant growth. The researchers now plan to investigate how the immune system and nutrition are linked in plants.

More information: Stéphane Hacquard et al. Survival trade-offs in plant roots during colonization by closely related beneficial and pathogenic fungi, *Nature Communications* (2016). DOI: 10.1038/ncomms11362

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