Evolution of root nodule symbiosis with nitrogen-fixing bacteria

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Nitrogen is essential for all plants and animals, but despite being surrounded by it—the element constitutes 79% of air on earth—only a few bacteria can absorb it directly from the environment. All other species are ultimately dependent on these microbes as a source.

A new paper published this week in the open-access journal *PLoS Biology* investigates the genetics behind the symbiotic relationship between these nitrogen-fixing bacteria and plants, and presents evidence of specific genetic changes that might have led to the evolution of symbioses with nitrogen-fixing bacteria from a more ancient form of symbiosis.

About 80% of all land plants have a symbiotic relationship with fungi of the phylum Glomeromycota. The fungus penetrates cells in the plant's roots, and provides the plant with phosphates and other nutrients from the soil. This kind of symbiosis is called an arbuscular mycorrhiza, and evolved more than 400 million years ago. Professor Martin Parniske and colleagues started their study by looking at genes known to be involved in arbuscular mycorrhiza, to see whether they could find evidence of any specific genetic differences in plants that form symbioses also with nitrogen-fixing bacteria.

"In this so-called root nodule symbiosis bacteria live in the root cells of the host plants, where they bind elementary nitrogen from the air in special organs, the nodules," says Parniske. In return, the microbes get high-energy carbohydrates produced by photosynthesis in the host plant.

It had already been speculated that genes involved in the arbuscular mycorrhiza symbiosis might have been recruited for nodulation, as these symbioses both involve intracellular relationships. One clue was that several genes, including the so-called “symbiosis-receptor-kinase-gene” (SYMRK), are involved in a genetic program that links arbuscular mycorrhiza and one form of bacterial nodule symbiosis. And the analysis of SYMRK in several species of plant provided the striking evidence that Parniske and his colleagues had been hoping for.

“Our results reveal that an expansion of the functions of SYMRK constituted an important step in the evolution of intracellular nodule symbiosis,” reports Parniske. Most plants have a short version of SMYRK, which is required for AM symbiosis. A longer variant of SMYRK was found only in plants involved in the symbiotic relationships with nitrogen-fixing bacteria. Importantly, the longer version was found in both legumes (which form symbioses with rhizobia – the textbook nitrogen-fixing symbiosis) and in actinorhiza (such as alder) which form symbiotic relationships with frankia bacteria, about which there is little genetic information. The results therefore suggest “a common evolutionary origin of intracellular root symbioses with nitrogen-fixing bacteria.”

This work is an important step towards understanding the evolution of nitrogen-fixation in plants, and even whether plants that don’t form symbioses with nitrogen-fixing bacteria could be engineered to do so, thus increasing their nutritional value.

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