Fungi shifted plant balance of power

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A thallose liverwort, Lunularia cruciata.

Cooperating with fungi didn't just help the earliest plants spread across a barren, rocky landscape; it also played a decisive role in the rise of more complex plants with roots and leaves that make up most of today's flora.

That's the conclusion of a recent study, which used experiments on closely-related plants that are still around today to investigate how major environmental changes around 400 million years ago gave more complex new 'vascular' arrivals the edge over older, simpler 'non-vascular' plants like liverworts.

A sudden plunge in atmospheric CO_2 made these simpler plants' cooperative fungal networks far less capable of supplying them with enough nutrients to grow, compared to a corresponding improvement for their vascular rivals. Adding to the problem, the upstarts were starting to outcompete them for light.

Also known as 'higher plants', vascular plants are far more anatomically complex than non-vascular ones, and their appearance saw the birth of innovations like leaves, stems and roots. The new conditions didn't just reward such novelties; they pushed evolutionary lineages further down the path towards complexity, helping shape the rich plant life we see today.

"The liverworts and other non-vascular plants were getting shaded out by plants with roots, leaves and stems, and they were faced with a huge drop in CO2 levels that made their fungal networks far less effective," says Dr. Katie Field, a plant scientist at the University of Sheffield and lead author of the paper, which appears in *Nature Communications*. "They really were up against it." They quickly lost the top spot; and have never regained it since, though their relations are still around today.

Most plants work with specialised fungi in a mutually-beneficial relationship. Networks of fine fungal filaments attach themselves to plant roots and work to free scarce nutrients like phosphorus from the soil. They pass these to the plant, and in return get carbon-rich sugars that the plant has made through photosynthesis.

This cooperative relationship, known as a 'symbiosis', dramatically improves plants' ability to grow and flourish. Scientists think it may well have been essential in letting them start to spread across the land surface in the first place around 450 million years ago.

Back then in the Devonian era, there was no soil as we know it today; most areas were little more than bare rock. Especially for rootless non-vascular plants, getting nutrients from this unpromising growing medium might have been impossible without the services of fungi.

"It's an ancient partnership, and one hypothesis is that the liverworts would never have been able to access the minerals they needed from the ground without it," explains Field.

Fossils show that early vascular plants like club mosses and lycophytes appeared around 385 to 400 million years ago. Around the same time there was a dramatic 90 per cent drop in the concentration of CO_2 in the air, perhaps caused in part by the rapid spread of plant life, which absorbs the gas to photosynthesize.

Scientists have long understood that such a sudden change in atmospheric conditions would have seriously affected the terrestrial flora, but until now they had no experimental evidence about the effect on different kinds of plant.

The team grew plant types under controlled conditions - liverworts very similar to the earliest fossil non-vascular plants, ferns that are very close to the earliest vascular plants, and a vascular plant that evolved relatively recently, the ribwort plantain.

These plants grew in special compartments with a fine mesh that prevented the plants' roots from getting out beyond the central core but allowed the passage of fungal filaments. So if the plants managed to get at the nutrients beyond, they must have done so through the fungal partnership.

Some of each kind of plant were kept in CO_2-rich conditions akin to those in the early Devonian, while others faced a CO_2-poor environment like the modern one. At the end of the growing period, the scientists ground up each plant and analyzed its chemical composition. This let them work out how much carbon it had absorbed, how much phosphorus it had been able to get from the soil, and therefore how much phosphorus it got back from the fungi per unit of carbon invested - the efficiency of its fungal network.

They found that in the early high-CO2 conditions, the liverworts held their own, but that when levels of the gas dropped their fungal efficiency plummeted - probably because they had smaller fungal networks to start with. Vascular plants, in contrast, saw a slight increase to their fungal efficiency. Combined with their ability to grow above the ground on stems to get closer to the sun, this gave them a decisive evolutionary advantage.

These days non-vascular plants are generally confined to wet, shady or otherwise difficult environments. They're often found playing a similar role as early colonizers of disturbed or bare habitats that their distant forebears did when they first took to the land hundreds of millions of years ago, but in most areas vascular plants like grasses and trees have taken over.

More information: Contrasting arbuscular mycorrhizal responses of vascular and non-vascular plants to a simulated Palaeozoic CO2 decline. Katie J. Field, et al. Beerling. *Nature Communications* 3, Article number: 835. doi:10.1038/ncomms1831

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