Dry conditions spurred advanced photosynthesis

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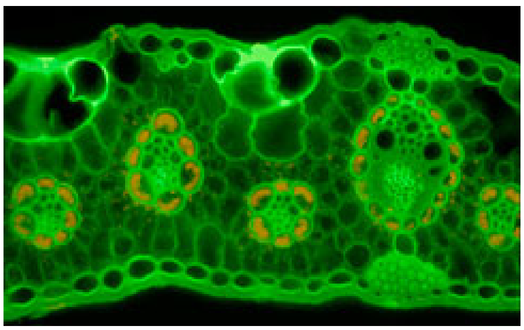

A cross-section of the leaf of a plant that uses C4 photosynthesis.

The need to conserve water played a vital role in driving plants to evolve a specialised form of photosynthesis, scientists have shown.

Most plants still use 'C3 photosynthesis' to make energy from sunlight and carbon dioxide (CO2). In the process they lose a lot of water through the pores in their leaves, and in dry conditions this can kill them.

So-called 'C4 photosynthesis', often used by members of the grass family, adds extra elements to the basic design. The chemical reaction that powers C3 photosynthesis happens in sealed compartments deep within a plant's leaves rather than near the surface. This lets the plant feed the reaction with concentrated CO2, which is more efficient and means they lose less water.

Until recently scientists emphasized the need to use CO_2 more efficiently in explaining the development of C4 photosynthesis, but this research suggests limiting water loss was also crucial.

"A basic problem for land plants is that to allow photosynthesis to make food from carbon dioxide, holes have to be opened up in their waterproof skin," explains Dr. Colin Osborne of the University of Sheffield, lead author of the paper. That wasn't a huge problem in the moist tropical forest understorey, but as CO_2 levels dropped and tree cover got patchier due to global environmental change, many species had to adapt to life in dry, open places that would ultimately become grasslands and desert.

The classical view has been that C4 photosynthesis developed from C3 in many separate plant groups largely because environmental change starting around 30 million years ago exposed plants to much lower CO_2 levels, and that photosynthesis had to become more efficient to cope.

The new research, published in Philosophical Transactions of the Royal Society *B*, draws on models of how plants draw water from the soil to suggest that, while these factors were important, drought may have been just as vital in spurring the development of C4 photosynthesis. "The classic view has emphasized carbon, but we're saying that the problem of water loss from leaves could have had as much to do with it," says Osborne.

"It's a paradox - we know that C4 plants use water more efficiently, but if you look at the grasses globally, they're not generally in the driest areas," he adds. "But by looking at the evolutionary tree of life, we can see that C4 tended to evolve when grasses were migrating into more open environments, as their existing forest habitats were shrinking and opening up."

Enslaved bacteria

A plant needs continuous columns of water along the pathways leading from its roots to its foliage; as water evaporates from the leaves, hydraulic forces draw more up from the ground just as water is drawn up a siphon tube. If these water chains break, the plant can no longer pull up water from its roots, and must spend energy repairing the hydraulic connections to avoid dehydration. If this happens too often, the plant dies.

C3 photosynthesis has evolved just once. Early single-celled organisms called cyanobacteria developed the trick of turning sunlight into energy, and were eventually somehow captured or domesticated by more complex organisms and put to work inside their cells as the microscopic structures called chloroplasts, which do the heavy lifting of photosynthesis. As Osborne puts it, "Plant leaves are full of enslaved bacteria." In contrast, scientists now think the more specialized C4 variant, which is a kind of add-on to the classic technique, has independently arisen more than 60 times.

C4 photosynthesis isn't the only solution to dry conditions, and it's not the most effective at extremes - truly arid environments like deserts are generally dominated not by grasses and other C4 plants, but by succulents like cacti. These use a different technique, which involves absorbing lots of CO_2 overnight and storing it up for use during the day. This means the plant doesn't have to open its pores in the heat of the daytime, minimizing evaporation.

Osborne is now carrying out experiments with co-author Lawren Sack of UCLA, aiming to test these findings by comparing how C4 plants and closely-related C3 species handle drought.

More information: Evolution of C4 plants: a new hypothesis for an interaction of CO_2 and water relations mediated by plant hydraulics. Colin P Osborne and Lawren Sack, *Phil. Trans. R. Soc. B,* 19 February 2012. Vol. 367, no. 1588, 583-600. doi: 10.1098/rstb.2011.0261

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