Discovering how cyanobacteria form patterns for nitrogen fixation

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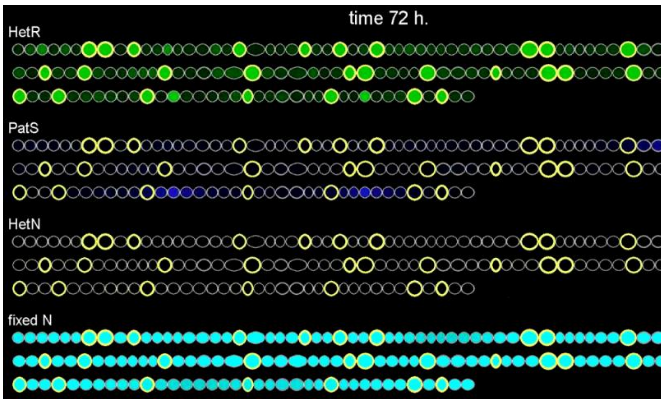

Computer simulation of the evolution of a filament of cyanobacteria. Credit: UC3M

Scientists at Universidad Carlos III de Madrid (UC3M) have analyzed the process of nitrogen fixation by cyanobacteria, creating a mathematical model that reveals the patterns they form. In these patterns, approximately one out of 10 cells in cyanobacteria filaments fixes nitrogen, while the remaining nine carry out photosynthesis. These microorganisms are fundamental to life on Earth because they produce much of the planet's oxygen and convert nitrogen into chemical forms that can be used by any life form.

Almost all the oxygen in the atmosphere today was produced by cyanobacteria millions of years ago; cyanobacteria continue to produce between 20 and 30 percent of the photosynthetic activity on Earth. Along with other microorganisms called Archaea, they are the only living beings able to convert nitrogen from the atmosphere into chemical forms that can be used by any life form. According to one of the authors of the research, Saúl Ares, "Without cyanobacteria, neither human beings nor any other complex living organisms could survive on Earth, because we would not have oxygen to breathe or nitrogen with which to build complex molecules like DNA and the proteins in our bodies."

This work, which has recently been published in the journal *PNAS* (*Proceedings of the National Academy of Sciences*), focuses on the process of nitrogen fixation by cyanobacteria of the genus Anabaena, in which cells stick to each other forming a filament. When there is enough nitrogen in the environment, all the cells in the filament perform photosynthesis. However, in conditions of fixed nitrogen deprivation, about one in every ten cells—distributed fairly regularly throughout the filament—diversify into a distinct cell type called a heterocyst. Heterocysts are unable to perform photosynthesis, but instead fix nitrogen and share fixed nitrogen with the rest of the filament's cells.

Ares, who developed this line of research at UC3M's Department of Mathematics explains: "We have used what is known about the genetics of the process to create a mathematical model for the formation and maintenance of the heterocyst pattern." He goes on to say, "Our theory reproduces the experimental observations and has allowed us to predict a new kind of mechanism, not proposed until now, which should play a role in the maintenance of the pattern."

One of the most surprising aspects emphasized by the researchers is the regularity in the pattern formed by cyanobacteria. "These bacteria are able to 'count to 10.' One in every 10 fixes nitrogen, leaving a gap of nine, and then the 10th one again fixes nitrogen," says Ares.

Until now, ideas relative to the formation of this pattern were only qualitative and their consistency had not been proven. "By making a mathematical model, we have been able to prove that these ideas work, but we have also seen that the process is not completely explained, because actually a new mechanism is needed—the nitrogen that produces the cells is playing a role," says the researcher.

More information: Javier Muñoz-García et al. Formation and maintenance of nitrogen-fixing cell patterns in filamentous cyanobacteria, *Proceedings of the National Academy of Sciences* (2016). DOI: 10.1073/pnas.1524383113