The Evolution of Our Fungi Relatives

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Fungi studied by researchers in Duke Forest.

In the latest installment of a major international effort to probe the origins of species, a team of scientists has reconstructed the early evolution of fungi, the biological kingdom now believed to be animals' closest relatives.

In a report published Oct. 19 in the journal *Nature*, the researchers outlined evidence that the ancestors of mushrooms, lichens and various other fungi may have lost their original wiggling taillike "flagellae" on several different occasions as they evolved from water to land environments while branching off from animals in the process.

Their losses of flagellae "coincided with the evolution of new mechanisms of spore dispersal, such as aerial dispersal," said the report, whose first author is Timothy James, a postdoctoral investigator at Duke University who recently relocated to Sweden's Uppsala University and the Swedish Agricultural University. Spores are tiny biological bodies, often consisting of a single cell, that fungi and certain other organisms use to reproduce themselves.

The research team represented a collaboration of 70 scientists working at 35 different institutions, and the scientists analyzed information from six key genetic regions in almost 200 different contemporary species to decipher the earliest days of fungi and their various relations.

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The work was supported by the National Science Foundation under a special program that encourages large scientific collaborations to address major scientific questions related to the origins of species.

"Results from the team's research suggest new, hypothesized relationships in which fungi called chytridiomycetes, which have self-propelling flagellated spores, are most closely related to fungi with spores that lack flagella," James said in an interview.

These "unpredicted relationships link fungi that produce motile spores with fungi that have lost spore motility but evolved dispersal by explosive mechanisms," James said.

An example of "explosive" dispersal includes mushroom varieties that "shoot out" spores that can regenerate wherever they land, said study co-author Rytas Vilgalys , a Duke biology professor who specializes in fungi and who supervised James' postdoctoral research.

According to Vilgalys, what makes a fungus a fungus is not the way it propagates but how it feeds. Among the eukaryotes -- a broad spectrum of organisms having complex cellular architectures that include a nucleus -- fungi are the only ones that can digest food outside their bodies, he said.

"They release enzymes to do that and then absorb the nutrients," he said. "That's why they are the primary decomposers in land-based ecosystems, and many are also decomposers in aquatic ecosystems."

Vilgalys said scientists estimate that the lineage that included both fungi and animals split off from other eukaryotes about 1 billion years ago, while fungi and plants separated about 600 million years ago.

With fossil evidence for fungi practically nonexistent, scientists have had to rely on "molecular data" to make such estimates, Vilgalys said, referring to studies that compare the genetic relationships of various present-day species to deduce which might date back the furthest.

"It was only in the early '90s when molecular data showed pretty conclusively that animals and fungi are each other's closest relatives, and that they diverged after an earlier split that led to land plants," he said. "What this study is trying to address is what the first fungi looked like."

To answer such questions, fungal scientists, or mycologists, began years of collaborating under the National Science Foundation's "Tree of Life" program, which has distributed approximately $3 million to labs at Duke and elsewhere.

"The idea was that big problems in biology require the same approach that physicists use," Vilgalys said. "Instead of competing with each other, everyone needs to work on a different piece of the puzzle and then contribute their results to assemble in one big data matrix."

At Duke, Vilgalys' group joined another headed by associate biology professor Francois Lutzoni to receive roughly $1 million of the Tree of Life funding. Lutzoni is a co-author of the current study, and Frank Kauff, a postdoctoral researcher in Lutzoni's group, is the report's second author.

Kauff used a computer database he helped create, called the Web Accessible Sequence Analysis for Biological Inference, to process and analyze all of the collected genetic information. That work was performed on a large computer "cluster farm" developed by Duke's Center for Computational Science, Engineering and Medicine.

Vilgalys said that James, as the report's first author, interacted with scientists at Duke and the other collaborating institutions to analyze six different gene regions where relationships among the five currently classified fungi groups could be tied together.

"Because we are working with about 150 existing species out of a total of at least 1.5 million different fungi, we can only make inferences about these lineages," Vilgalys cautioned. "We used a variety of different ways of inferring the early branching pattern."

Starting with what the evidence inferred to be species with the longest family trees, and working up to the more recent additions, the scientists looked for signs of branching relationships amid increasing complexity.

"The most interesting aspect suggests that, more than once, ancestors changed from having flagellae and a one-celled spore stage that moved around to adapting to life on land," Vilgalys said. "In the process, they may have lost their flagellae as few as three times or as many as six. And in every instance, they evolved a different novel way of dispersing spores."

For example, contemporary mushrooms, although rooted to the ground, can still spread their kinds over long or short distances through their spores, which may be broadcast by explosive volleys or more passively through windborne dispersion.

"Trufflelike fungi, on the other hand, produce their spores in odiferous masses that are attractive to insects or mammals that then serve to disperse them," Vilgalys said.

"Virtually every lineage of terrestrial fungi has some novel dispersal mechanism, and surviving aquatic fungi have their own adaptations," he added.

James said the new research suggests that the first organisms to branch off from the fungi kingdom were parasites similar to the modern-day chytidiomycete fungus known as Rozella.

Ancestors similar to Rozella appear to have directly given rise to parasites similar to contemporary nonfungal organisms known as microsporidia, which lack swimming spores but instead inject spores through a long tube directly into a receiving cell.

The scientists' genetic roadmap also pinpoints a location the next branch down the evolutionary "tree" where the animal kingdom diverged from the fungi, Vilgalys said. And evidence suggests that most of those earliest animals got around with the aid of flagellae.

Source: Duke University