

Space Life Sciences Research Highlights

Spaceflight Allows Botanists To Probe Fundamental Questions About Plants

*When plants grow on the International Space Station, or even take a trip on an airplane, their gene activity changes in response to differences in gravity and other environmental qualities. NASA-funded botanists Robert Ferl and Anna-Lisa Paul of the University of Florida monitor those changes in the model plant *Arabidopsis thaliana*. They have found that different parts of the plant respond to spaceflight in their own unique ways. They also developed a method to watch the activity of individual genes within specific plant cells. This work will not only help astronauts to be better gardeners, but also reveal key information about how plants handle challenging environments.*

Astronauts on the International Space Station (ISS) may be able to eat fresh lettuce courtesy of the Station's VEGGIE plant growth facility, but if humans are to become permanent residents of space, the Moon, or Mars, there is still a lot we have to learn.

“We are better gardeners in space than we were 20 years ago” says NASA-funded researcher Robert Ferl, director of the Interdisciplinary Center for Biotechnology Research at the University of Florida (UF), while acknowledging that there is still a great deal we don't know about spaceflight's impact on plant biology. “Plants that are grown in space are definitely doing something different than they do here on Earth,” he adds.

For more than two decades, Ferl and his colleague Anna-Lisa Paul, a research professor in UF's Department of Horticultural Sciences and the Graduate Program in Plant Molecular and Cellular Biology, have worked with the model organism *Arabidopsis thaliana*, or thale cress, to understand better what happens to plants during spaceflight. Their research, honored with a 2014 NASA award for Most Compelling Results from the ISS, will not only help future astronauts to improve their space gardening skills but will also reveal essential knowledge about plant biology, the pair says.

Ferl reminds us of how unusual an experience spaceflight is for terrestrial organisms. “The combined challenges of spaceflight that require organisms to adapt to such a unique environment,” Ferl says, “gives us, as scientists, the opportunity to probe truly deep, fundamental questions” that we can apply to plants growing in any environment.

Plant Parts Respond Differently to Spaceflight

Life on the ISS is unlike life on Earth. Due to changes in the effect of gravity in the spaceflight environment, substances like air and water don't move in the same way as they do on the ground. But even if Earth's gravity could be simulated, plants would still find spaceflight to be an odd experience, notes Ferl. “There are a lot of things that are different...out in the space station than here, such as



Robert Ferl (right) and Anna-Lisa Paul (left) from the University of Florida, recipients of an award for Most Compelling Results from the International Space Station, say that they are not typical botanists.

light, vibration, and the composition of gases in the air. If you know nothing about how plants or organisms adapt to living in space you might think that there are some universal things that have to be adapted,” Ferl states. If that were true, however, all parts of an organism would respond in the same way to the spaceflight environment. But that's not what happens in *Arabidopsis*, as Ferl, Paul, and their colleagues reported in a 2013 article in the journal *BMC Plant Biology*.

That paper describes experiments conducted during 2009 and 2010 in which the investigators sent *Arabidopsis* seeds on agar plates to the ISS. Upon germination, the tiny plants grew on the plates for 12 days, after which they were harvested. A similar set of plants were grown on the ground as a control. Back in the lab, three parts of the plant—roots, leaves, and hypocotyls— from both the flight and ground sets were analyzed for patterns in gene expression. “There are some common themes throughout,” says Paul, but each part of the plant had a distinct pattern of response to life in microgravity. In the roots, for instance, genes responsible for cell wall remodeling and root growth were differentially expressed. A different set

of genes, some of which are also involved in cell wall remodeling were altered in leaf tissue. Interestingly, genes involved in defenses against pathogenic microbes and predators were upregulated in these organs.

Characterization of the gene expression patterns of plants grown in spaceflight has given Ferl and Paul clues about the biological systems regulating plant growth and development that they likely would not have acquired by studying plants solely on the ground, as Paul notes that gravity may actually be masking some of these regulatory mechanisms. For example, Ferl and Paul detected changes in the expression of genes involved in light sensing in both roots and leaf tissue, warranting further study of how plant light and gravity perception mechanisms interact with each other.

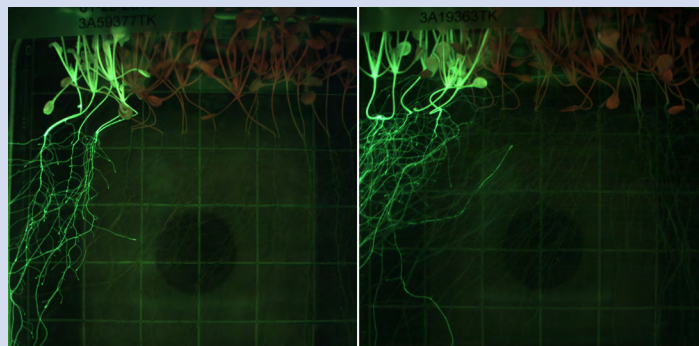
Watching Genes In Action

Gene expression profiles are useful for seeing what happens within whole plants or their separate parts, but Ferl and Paul have also engineered *Arabidopsis* plants to watch what is happening within individual cells. To do this, the team labels a gene of interest with additional DNA encoding for production of green fluorescence protein, or GFP, resulting in a protein whose expression and location can be tracked by fluorescence microscopy, letting investigators see gene expression in specific cells. “As long as we have the proper optics, we can watch that gene being expressed in real time during the growth and development of plants on orbit, and compare that to plants grown on Earth,” Ferl explains.

For example, when the team used a reporter gene called DR5:GFP, which is sensitive to the plant hormone auxin, the researchers were able to watch as the gene was expressed in hypocotyl cells at low auxin levels, then high, then low again. That level of precision in both time and space would not be possible with just gene expression profiling.

The technique allows researchers to monitor in real time what is going on inside plants during their life on orbit, Ferl notes. And by tagging gene products with different fluorescent colors, the team will be able to monitor multiple genes simultaneously within a single plant.

Most people would be astonished to know that a plant senses that it is in space or even on an airplane flight, says Ferl. “Even on a commercial jet liner, a plant changes metabolism to be in that environment, and we can read those changes.” That knowledge has led the team to broaden the scope of their research to not only what happens during spaceflight but also during the other phases of space travel, such as takeoff and landing. “What will happen when there’s an acceleration put on the vehicle and that vehicle is going to land on the Moon?” Ferl



To watch what is happening in individual cells of *Arabidopsis* plants, Ferl and Paul label genes with green fluorescent protein. Plants are then grown on the ground (left) and on the ISS (right).
Credit: A-L Paul and RJ Ferl

wonders. So the investigators take *Arabidopsis* plants on trips on the “Weightless Wonder,” an airplane that uses a series of parabolic arcs to simulate the extremes of microgravity and hypergravity. They have found that, even after just a few parabolas, plants’ gene expression is changing.

Ferl and Paul are now investigating what happens to *Arabidopsis* plant anatomy and function due to changes in gene expression levels, which could give insight into how the plants adapt to spaceflight and other novel environments. *Arabidopsis* will be sent on a suborbital flight experiment to study how the plants transition from normal gravity to the microgravity environment.

If humans are to move to the Moon or Mars, we need to understand the limits of terrestrial life, Ferl says. “The feedback loop is that as we learn about enabling plants to do more in challenging environments, we can also affect what kinds of things we ask plants to do on Earth to better enable us to extract every resource we can out of everything we grow.”

Further Reading

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