Researchers Achieve Breakthrough by Growing Plants from "Seed to Seed" in Space

Researchers led by NASA-supported investigator Mary E. Musgrave have succeeded in growing plants through a full life cycle—from seed to seed—in space, demonstrating that gravity is not required for plants to reproduce. The experiments were conducted aboard the Russian space station Mir by the first "farmer in space," astronaut C. Michael Foale.

Humans could not live on Earth without plants. By taking in carbon dioxide and releasing oxygen, plants help to provide the air we breathe. Plants also release water vapor that is "recycled" as rain. Last but not least, plants provide most of the food to support the Earth's population.

The same qualities that make plants essential to life on Earth make them highly desirable on long-term human space missions. If plants could be grown in space, they could provide oxygen, water regeneration, and food for astronauts. Plants have also been shown to offer psychological comfort to crew members on long space missions.

However, getting plants to grow through a full life cycle—from planted seed to harvested seed—in microgravity has proved an elusive goal for space biologists. In many experiments over the last 40 years, plants in space either died before they flowered or flowered but produced no seeds. Some scientists speculated that plants would never produce seeds in microgravity because gravity is essential to the plant life cycle.

By successfully growing plants from seed to seed on the Mir space station, Mary E. Musgrave, Ph.D., Associate Dean of the College of Natural Sciences and Mathematics at the University of Massachusetts in Amherst, and her colleagues have demonstrated that gravity is not absolutely required for any step in the plant life cycle.

Early Clues

In trying to understand what might be limiting plant reproduction in space, Musgrave and her associates used *Arabidopsis thaliana* to look at different segments of the reproductive process during short experiments on the shuttle. The first experiment showed that flowers failed in closed chambers on the shuttle, even though they developed normally on the ground when grown in the same kind of chambers. Analysis showed that the space flight plants ran out of carbon dioxide because the lack of convective air movement in microgravity prevented mixing inside the chamber. Just as humans fail to thrive when starved of oxygen, plants cannot thrive when starved of carbon dioxide.

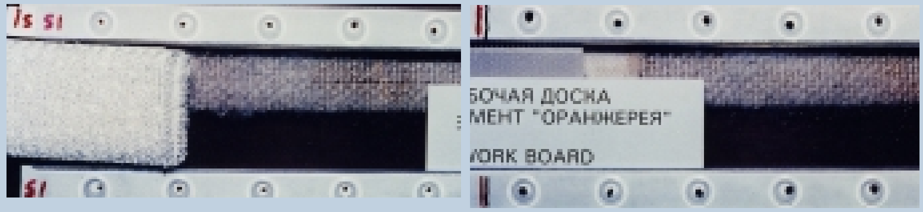
In a preliminary experiment aboard the space shuttle, Astronaut Kevin Kregel uses bee sticks to collect pollen grains from mature plants and transfer pollen to other plants for pollination and subsequent seed development. The same procedure was used by Astronaut Mike Foale aboard Mir for the Brassica experiments.

When the researchers devised a system for keeping the plants constantly resupplied with carbon dioxide, the plants literally bloomed. "We got perfect flowers and perfectly formed young seeds that were indistinguishable from the ground controls," says Musgrave. The investigators thus proved that, in the right conditions, plants could produce seeds in microgravity.

Seed-to-Seed Success in Space

The logical next step was to try to grow plants through a full life cycle in space. These experiments were conducted on Mir during the fifth increment of the Shuttle/Mir program in 1997. This time the plant used was *Brassica rapa*, a close relative of *Arabidopsis* that is larger and also has a short life cycle.

Another feature of *Brassica* that made it suitable for these experiments is that its flowers must be pollinated by hand (unlike *Arabidopsis*, which self-pollinates). “It was important for us to know exactly when the flowers were pollinated so we could tell whether the seeds were developing at an appropriate rate,” explains Musgrave.



Planting strips containing seeds from Brassica plants grown in space aboard the Mir space station (left). Seeds were smaller than normal, and smaller than control seeds grown on the ground (right). Astronaut Mike Foale then used these planting strips to replant the seeds in space; the resulting second-generation plants were smaller than controls.

The shuttle delivered to Mir plastic planting strips preloaded with dry *Brassica* seeds. Astronaut C. Michael Foale planted the seed strips in a specially designed, well-ventilated plant growth chamber. When the seeds grew and produced flowers, Foale pollinated them by hand using a “bee stick” (the body of a dried bee glued to a toothpick).

The pollinated plants produced seed pods. When the pods matured and dried, Foale collected the seeds and replanted them, producing a second generation of plants from seeds grown and planted in space. “He became the first farmer in space,” says Musgrave. The astronaut’s other duties included fixing plant samples in chemical preservative and freezing them in nitrogen to preserve them for later analysis on the ground.

Delayed Seed Development

The plants grown in space from the original seeds sent from Earth were normal in every way, Musgrave and her colleagues found. However, although these plants produced seed pods that were normal both in number and size, the seeds themselves—and the second-generation plants that grew from them—were smaller than normal, compared with control seeds and plants grown during the same time period on the ground.

“The seeds grown in space were developmentally delayed,” explains Musgrave. “They failed to ripen normally.” The space-grown seeds also exhibited subtle differences in composition—they retained large amounts of starch when they should have been storing protein and lipid—compared with the ground controls.

“We conclude from these experiments that gravity is not absolutely essential to the life cycle of plants,” says Musgrave. “However, the absence of gravity during space flight is responsible for differences in seed quality.”

Because the seed pods were normal, she and her colleagues suspect that stresses occurring late in the seed development process are responsible for the smaller size and poorer quality of the seeds produced in space and for their failure to ripen normally. The investigators are now focusing on trying to understand how the lack of convection in microgravity would change the microenvironment inside the closed seed pods, and how this would affect seed development.

Delayed seed maturity is a common—and costly—problem in agriculture on Earth, Musgrave notes. “Our work has shown that subtle changes in the microenvironment of the seed pod can adversely affect seed ripening,” she says. Achieving a better understanding of the factors that influence the seed microenvironment could ultimately benefit farmers on Earth as well as future farmers in space.

References

1. Kuang A; Xiao Y; McClure G; Musgrave ME. Influence of microgravity on ultrastructure and storage reserves in seeds of *Brassica rapa* L. *Annals of Botany* 85:851-9, 2000.
2. Musgrave ME; Kuang A; Xiao Y; Stout SC; Bingham GE; Briarty LG; Levinskikh MA; Sychev VN; Podolski IG. Gravity independence of seed-to-seed cycling in *Brassica rapa*. *Planta* 210(3):400-6, 2000.
3. Kuang A; Popova A; Xiao Y; Musgrave ME. Pollination and embryo development in *Brassica rapa* L. in microgravity. *International Journal of Plant Science* 161(2):203-11, 2000.
4. Musgrave ME; Kuang A; Matthews SW. Plant reproduction during spaceflight: importance of the gaseous environment. *Planta* 203:S177-84, 1997.

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