Space Life Sciences Research Highlights

How Plants Respond to Gravity: NASA-Supported Researchers Find Genetic Clues

Unraveling the fundamental mechanisms by which plants respond to gravity is the focus of Patrick Masson's research. Masson's team has identified two genes that are important to the way plants perceive and respond to gravity. Understanding these fundamental mechanisms could pave the way for techniques not only for improving agricultural crop production on Earth, but also for growing crops during space flight or on other planets.

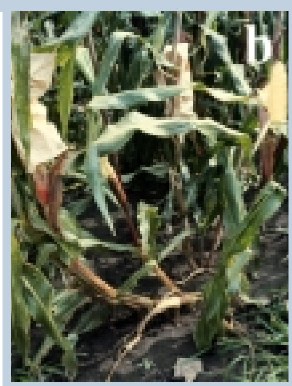
A cornfield after a heavy spring rainstorm can be a sorry sight—hundreds of young corn plants flattened by the force of the rain. Within a very short time, however, the corn begins to grow upright again. Why? In response to light, of course, but also in response to gravity.

"The plant can sense that it has been flattened—its direction of growth has been modified in comparison with the direction of gravity," says Patrick H. Masson, Associate Professor of Genetics at the University of Wisconsin, Madison. "So it activates a variety of processes that enable it to change its direction of growth."

That plants use gravity to guide their growth—ensuring that roots grow downward into the soil whereas shoots grow upward—has been known since 1806. In 1880, Charles Darwin postulated that the cells crucial for plants' perception of gravity are located at the tip of the root in a structure known as the root cap.

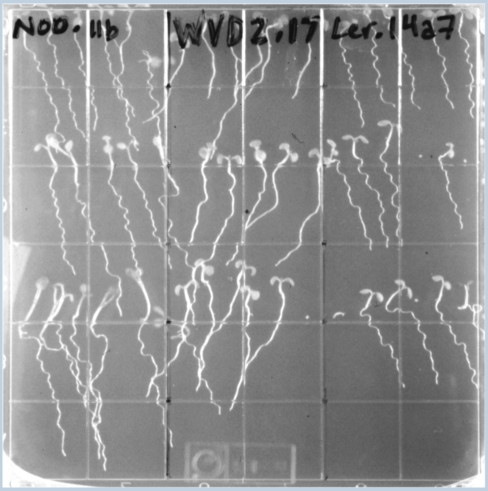
More than a hundred years later, however, there is much that scientists still do not understand about gravitropism—the process by which plants sense and respond to gravity. Masson and his colleagues are trying to change that.

Masson's laboratory is studying the molecular mechanisms by which plant roots use external stimuli—including gravity and touch—to direct their growth. From NASA's point of view, it is essential to know more about precisely how plants respond to gravity on Earth before embarking on any attempt to grow crops in environments with different gravity levels, such as on spacecraft, on the moon, or on another planet. "If you reorient a root within the gravity field—put it horizontally, for example—dense structures called plastids in the cells of the root cap will move to the new 'bottom' of the cell," says Masson. The root will also start to grow in a curved fashion, back toward the direction of gravity. This response occurs some distance away from the root cap.



The phenomenon of gravitropism, as illustrated by a corn field. The corn plants were flattened by a heavy storm (a), but after just a few hours their shoots have curved upward (b). This is due to the plants sensing and responding to the force of gravity. (Photograph from Plant Physiology 120(2): 343-350, 1999; reprinted with permission ©American Society of Plant Physiologists)

Masson and his colleagues are trying to understand, first, exactly how the cells of the root cap perceive that the plant's direction of growth relative to gravity has been altered and, second, exactly how that information is transmitted so that the plant responds by changing its direction of growth.



Skewed and wavy patterns of plant growth. Different strains of normal seedlings of Arabidopsis thaliana grown on agar placed vertically (left and right sides) grow slanted to the right and show a waving pattern. Seedlings of a mutant (center) skew to the left but do not wave. (Reprinted by permission ©American Society for Gravitational and Space Biology).

Most of the team's experiments are performed in *Arabidopsis thaliana*, a type of mustard plant. The plant has several advantages as a model system for genetic studies in plants, according to Masson. It is small, growing to a maximum height of about a foot. Its life cycle is short (six to eight weeks), which means that genetic studies can be completed in a short time. It can reproduce through either self-pollination or cross-pollination. Finally, it has a small genome that contains very little "junk DNA" (repetitive DNA sequences that have no obvious function), which increases the efficiency of genetic studies.

Masson's team has so far identified two genes that are important to the way plants perceive and respond to gravity. The first gene, known as *ARG1*, is believed to be involved in signal transduction—the process by which a physiological signal is produced and sent from the root cap (where the plant senses the direction of gravity) to the area where the plant's response to a change in the direction of gravity occurs.

The second gene, *AGR1*, carries the instructions for a protein that Masson and his team have shown is involved in transporting an important hormone-like chemical called auxin, which regulates numerous processes in plant growth and development. "Auxin appears to be at least part of the signal that is transmitted from the site of gravity sensing—the root cap—to the site of response," says Masson.

Analysis of the *AGR1* gene is increasing understanding of the molecular processes that affect the transport of auxin within plant cells and is providing important clues about the role of auxin in gravitropism, he says. In addition, it is shedding new light on fundamental processes in plant growth and development such as pattern formation—the process by which a plant embryo develops into a multicellular organism and embryonic plant cells develop into cells with specific functions.

To understand how plants might develop in microgravity, Masson and his team have created mutant *Arabidopsis* plants that are missing either the *ARG1* or the *AGR1* gene. "We are trying to understand what alternative stimuli the plant uses to direct its growth when its gravity response has been knocked out," says Masson.

"We are also studying how *Arabidopsis* roots respond to combinations of stimuli, such as a combination of gravity and touch. Under specific conditions, this can result in very complex and interesting patterns of growth, such as three-dimensional and wavy patterns. We have also identified genes that appear to modulate these patterns of growth but which, when mutated, do *not* result in defects in gravitropism." The study of these genes is providing insights into some of the molecular processes by which plant cells grow and develop.

References

1. Sedbrook JC; Chen R; Masson PH. ARG1 (altered response to gravity) encodes a DnaJ-like protein that potentially interacts with the cytoskeleton. *Proc Natl Acad Sci U S A* 96(3):1140-5, 1999.
2. Chen R; Hilson P; Sedbrook J; Rosen E; Caspar T; Masson PH. The Arabidopsis thaliana AGRAVITROPIC 1 gene encodes a component of the polar-auxin-transport efflux carrier. *Proc Natl Acad Sci U S A* 95(25):15112-7, 1998.
3. Chen R; Rosen E; Masson PH. Gravitropism in higher plants. *Plant Physiol* 120(2):343-50, 1999.

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