Lost in Space? Rooting for Plants in Zero Gravity

by Laura García Romañach

“There is no sensation of lying down”, NASA astronaut Sunita Williams explains. While floating in the middle of the International Space Station (ISS), her hair follows her movements in an eerily manner. With surprising agility, she continues moving through the chamber describing how she and her team live in the ISS.

“This is where we sleep”, she says, while pointing at some cubicles in the walls of the spaceship. “It really does not matter in which position we lie down: I can sleep in what I think it is a horizontal position, but it still feels like I am sleeping standing up. I do not have any sensation in my head that tells me I am horizontal or upside down” she says while smiling.

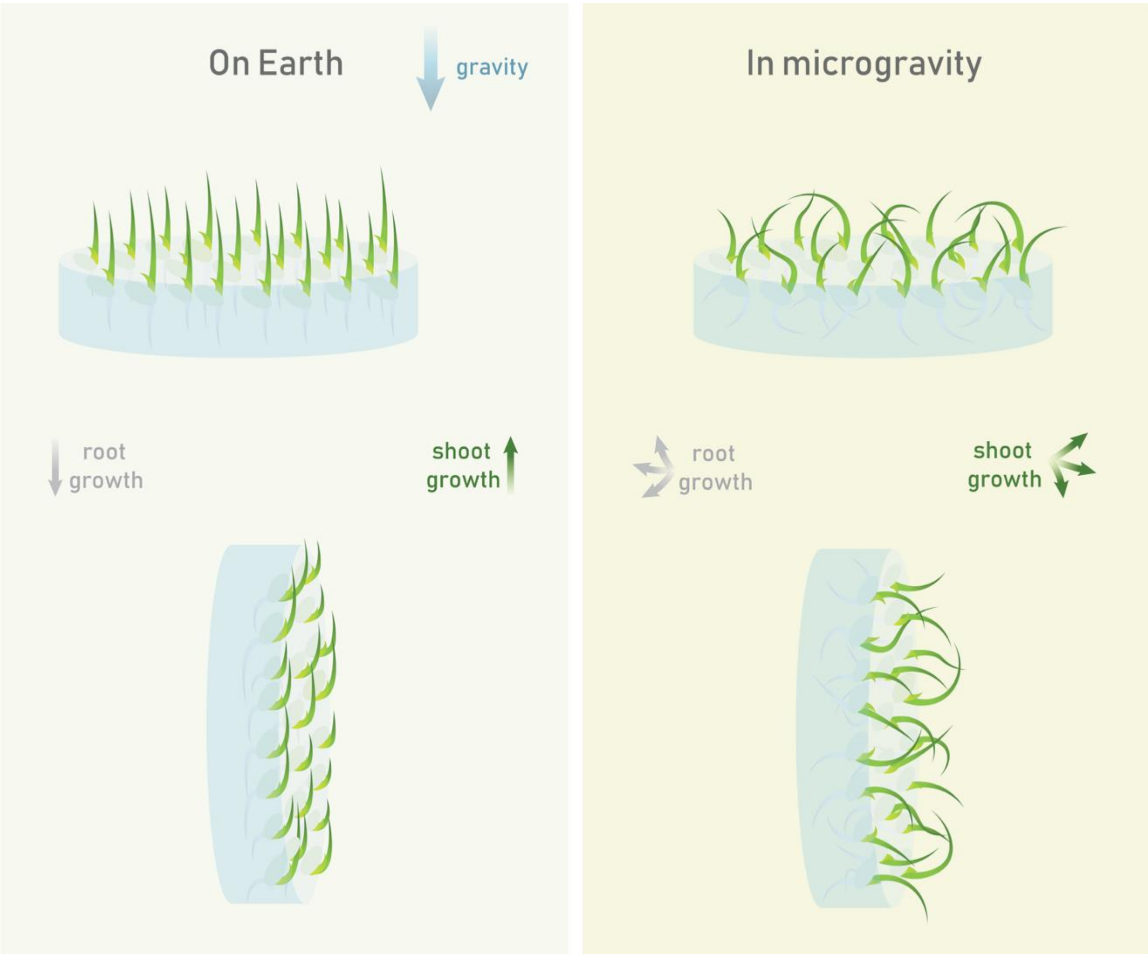
The effects of microgravity – a condition similar to zero gravity where things appear to have no weight – have been heavily documented in humans. Microgravity causes vital changes in the human body, and astronauts must keep a strict routine to minimize these effects. However, humans are not the only living beings in the ISS. This station contains several chambers where astronauts are trying to grow fruits and vegetables. The goal? To make life in space more sustainable for humans. The challenge? Plants can detect gravity – and the lack of it, which results in altered growth and development when plants are grown in space.

The role of gravity in plants

The most important problems astronauts can face while living in space are the lack of food, oxygen and water. Plants can overcome many of these challenges: they can generate oxygen from the carbon dioxide that humans release as we breathe out. In addition, they are a fresh food source full of nutrients and vitamins that are vital for astronauts during their trip.

The first time plants were fully grown in space was in 1982: the crew of the Soviet Salyut 7 space station managed to grow thale cress, a member of the mustard family. Despite observing some modifications in its growth and development, it was unprecedented that plants grown in space successfully flowered and produced seeds. Since then, several space agencies have managed to successfully grow and collect seeds from many other plant species, such as rice and peppers. In a groundbreaking achievement in 2022, researchers from the University of Florida even managed to grow plants on soil from the Moon.

Although these successes highlight the ability of plants to survive in space and in extraterrestrial soil, it also reveals the challenges caused by microgravity. Several studies have shown that in this environment, plants grow disoriented. In a study in Japan, scientists observed that rice plants grown in microgravity conditions seemed to lose the concept of "up" and "down". As a result, rice grew in random directions, very chaotically. However, rice grown on Earth had roots growing downwards – towards gravity, and shoots going upwards – away from gravity. In fact, even if rice (and other plant species) is grown at a right angle to the Earth's surface, its shoots and roots will rearrange to keep growing following the direction of gravity. Plants grown in simulated microgravity conditions are unable to rearrange their growth and keep growing in arbitrary directions. This random growth affects the development of the plant and its ability to produce healthy seeds. We now know that microgravity influences plant growth and development, but how do plants detect gravity on Earth?



Rice on Earth grows according to the direction of gravity, whereas rice in microgravity conditions grows in random directions. (Illustration by Laura García Romañach.)

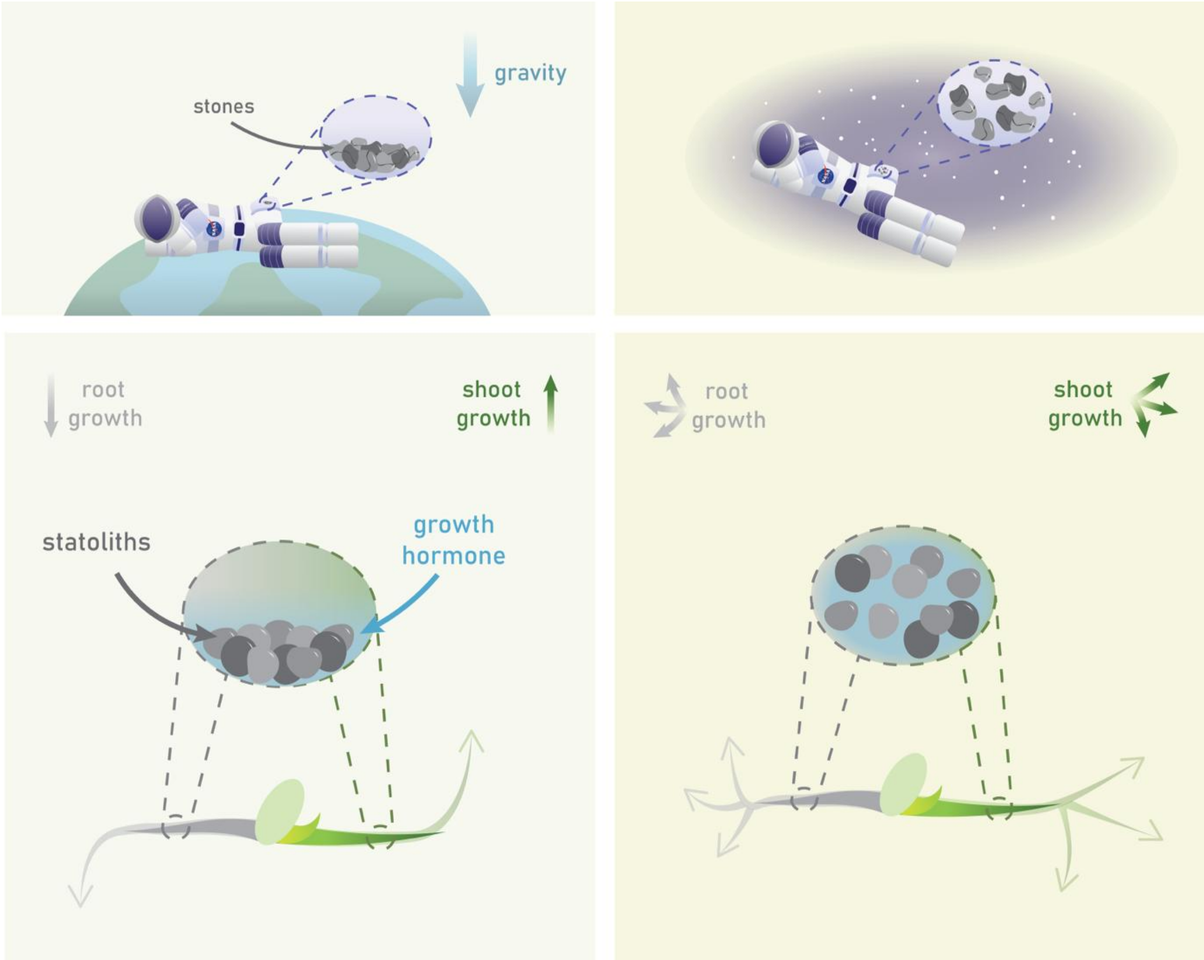
Gravitropism: a guide for growth

Gravitropism is the growth of different plant parts toward or away from gravity. This process consist of three sequential events: plants perceive gravity, they send signals, and finally respond to these signals by changing their direction of growth.

Gravity perception is a common mechanism in many plant species, from algae to trees. As plants moved from aquatic to terrestrial environments during evolution, developing their gravitropism was one way to survive. However, the complexity and type of mechanisms behind it varies widely. For example, some algae species can detect gravity and change their “swimming” direction according to it. Compared to land plants – those growing on the Earth’s surface – the gravitropic mechanism in algae is much simpler.

In land plants, roots and shoots grow in opposite directions to gravity. Despite this difference, they all share the same detection mechanism. The main players in this process are statoliths, sacks filled with starch -a type of sugar- that are found in both shoots and roots. These sacks can move inside the plant, but they always follow the direction of gravity. The physical movement of these sacks causes certain signals within the plants that leads to their “up” and “down” growth. In a way, the starch-filled sacks act like stones in our pocket. Whether we are standing or lying down, we always feel the stones weighing “down”, toward gravity. The stones are always indicating where “down” and “up” is, in a similar way that the starch filled sacks do for the plant.

The main player in gravity signaling and response is a growth hormone – yes, plant have hormones like us! If we imagine a plant lying down on the ground, the starch- filled sacks will accumulate on the lower side of the root and the shoot, following gravity. In response to the movement of the sacks – the gravity perception step of gravitropism, this plant hormone accumulates on the same side as the sacks. This means that most of the hormone is found on the lower side of the plant organs, whereas there is little amount of the growth hormone in the upper side. The difference in hormone accumulation is what causes curved growth and bending of the root or the shoot toward or away from gravity. After the bending, the statoliths will eventually move again and recalibrate, which will result in the straightening of the plant.



Sunita Williams lies down in her astronaut suit. On Earth, the stones in her pocket change position according to gravity and give her a feeling of “up” and “down”. In microgravity, the stones no longer weigh anything, and she loses any sense of direction. The mechanism of detecting gravity in plants is similar to what Sunita Williams has experienced. In plants, sugar-filled sacks called statoliths change position according to gravity and give the plant a sense of “up” and down”. The position of these sacks causes the accumulation of a growth hormone that triggers growth toward or away from gravity. In microgravity, the statoliths do not weigh and plants grow in random directions because they have lost any sense of direction. (Illustration by Laura García Romañach.)

Gravity affects the environment too – how do plants react to it?

Gravity not only influences the direction of plant growth but also affects the environment surrounding plants. In microgravity, liquids and gases present altered behaviors, which has serious consequences in plant development. For example, microgravity prevents the roots from taking up oxygen, which causes stress and damages plants. These and other adverse effects have led the ISS to start researching how to overcome the consequences of microgravity in plants. Several advances have already been made, such as using hydroponic or aeroponic systems – where plants only grow in water or mist with nutrients, avoiding the use of soil.

Microgravity also has some advantages in plant research: many scientists have reported that it is possible to discover plant responses to the environment that are usually masked by gravity. In a similar manner to gravitropism, plants can also detect light and grow toward it – a phenomenon known as phototropism. If you have ever placed a houseplant next to a window, you have probably noticed how it always leans toward it, no matter its initial orientation. On Earth, the growth of the plants is highly influenced by gravitropism and phototropism. This makes it difficult to distinguish whether they have specific responses to light or gravity. In microgravity –where the influence of gravity is removed– plants rely more on phototropism, which might lead to discovering novel mechanisms that regulate plant growth.

Understanding these mechanisms creates unique research opportunities that could benefit crop production in space and on Earth. As space missions become longer and more complex, learning how to grow plants outside our planet will be crucial for survival. Besides having a positive impact in future space missions, developing these strategies will also contribute to agricultural innovations in challenging environments on Earth. By continuing to study plant biology in space, we will be one step closer to make our planet livable for the generations to come.

Laura is a PhD student at SLU, currently investigating how age influences flowering in trees. Originally from Barcelona, Spain, she is fascinated by flowers and sadly allergic to pollen. She likes to walk in nature and photograph flowers in bloom, a hobby that runs in her family. She also has a passion for cooking, and she even considered studying at a culinary school before choosing a career in plant biology. In her free time, she is always up for a good conversation and loves to sing.

You can follow Laura on her LinkedIn page.