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Fertilizer Focus

Controlled release fertilizer research in space

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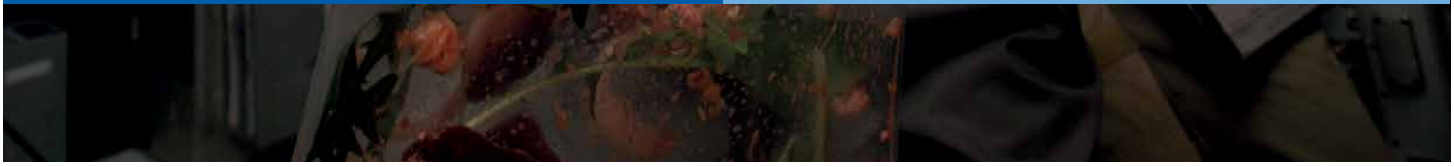

Mizuna to Mars

NASA collaborates with small business to develop new ways to grow plants in space

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In order to continue to push the boundaries of space exploration and establish a sustainable presence on the Moon, growing nutritious, flavourful food is key as we move toward longer-duration exploration missions.

The US National Aeronautics and Space Administration (NASA) has been on the cutting edge of innovative plant growth technology for decades, specifically working with hydroponic vertical gardening, LED (Light-Emitting Diode) lights, and controlled release fertilizers (CRF). Currently, researchers in the Space Crop Production laboratory at NASA's Kennedy Space Center are testing these technologies in real-time with the Vegetable Production System (Veggie), a plant growth unit on the International Space Station (ISS). The idea behind Veggie is elegantly simple, a self-contained low-power unit growing fresh, nutrient dense food on the ISS to supplement the astronaut's diet. Currently, there are two Veggie units on station, along with the Advanced Plant Habitat - a more sophisticated plant physiology research growth chamber.

Figure 1. Astronaut Jessica Meir harvesting mizuna on the International Space Station. *Photo Credit: NASA*

Presently, astronauts subsist primarily on packaged food, which has worked well to support an uninterrupted human presence in space on the ISS since 2 November 2000. However, this approach relies on frequent resupply missions. During a multi-year mission to Mars, the vitamins and quality of packaged food would degrade over time. Supplementation with fresh, nutritious vegetables and greens will provide essential nutrients while also enhancing dietary variety.

"In order to grow plants in space, you have to essentially forget everything you know about growing plants on earth," Gioia Massa, scientist on NASA Veggie project at the Kennedy Space Center explains, "We don't use soil, because soil is very non-uniform and that makes it hard to ensure a good outcome."

It is also not possible to water plants in the conventional way because of the lack of gravity. In place of soil, the Veggie plant-growth unit uses a porous, baked-clay substrate. That clay keeps the roots and the moisture in place, and helps to balance air and

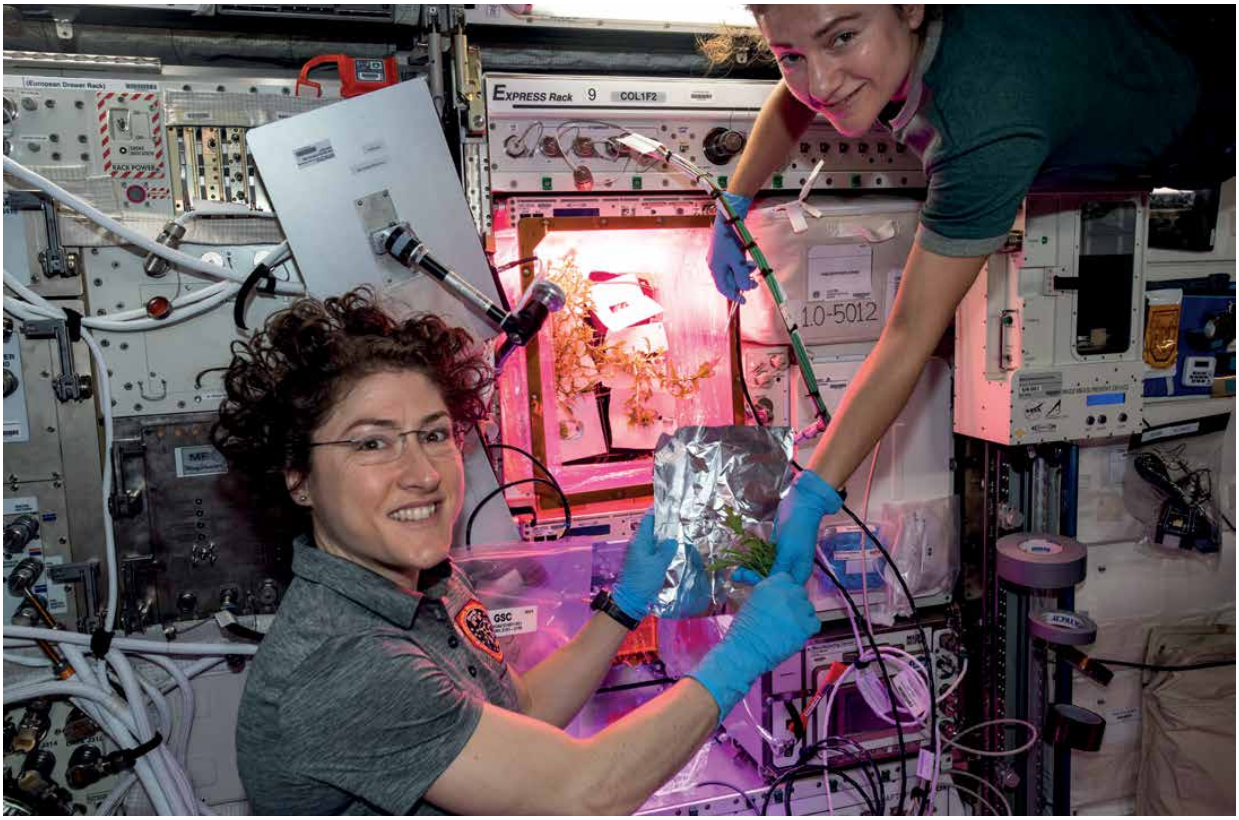

Figure 2. Astronauts Christina Koch and Jessica Meir on the ISS harvesting mizuna. *Photo Credit: NASA*

water in the root zone. However, it is entirely nutrient poor providing no nutrition for the plants - that is where control release fertilizer comes in.

Staged Nutrient Release

Ed Rosenthal, Founder and Chairman of Florikan, started working on control release fertilizer as a way to mitigate the negative environmental effects of over fertilizing plants. After observing standard growing practices for decades, Rosenthal explored the idea of separating each nutrient based on its relative solubility and when it was needed by the plant. The idea was that if he could coat individual nutrients in different polymers, with varying degrees of porosity, he could essentially control the delivery of fertilizers to individual plants, administering exactly the right amount of each nutrient at exactly the right stage of growing.

Innovations with CRF products have been utilized by NASA

The idea became a reality in the early 2000s and the new product, Staged Nutrient Release (SNR), was quickly adopted by growers. In 2004 Florikan was recognized by the state of Florida and by the National Society of Professional Engineers (NSPE) for developing one of the year's most innovative new products. The award came with 40 hours of free consulting with a Federal agency of the recipients choosing - Ed Rosenthal chose NASA. "I knew NASA was working with some really sophisticated polymers that hadn't yet made it into the commercial market," he said. The award associated with this recognition created the opportunity that initiated the relationship between NASA KSC and Florikan.

This award, and the ensuing collaboration, provided the technical expertise Rosenthal needed to begin working towards a new approach with control release fertilizers. By the end of 2008 the company had two new patents, the first for SNR and the second for the polymer coating the fertilizer used. The redesigned product is coated in semi-permeable polymers that control when and how much of each nutrient is released over a 6-12 month period.

NASA has been on the cutting edge of innovative plant growth technology for decades

The opportunity to consult with NASA scientists afforded Rosenthal the opportunity to redesign his products and fully reorient the company's goals. A few years after the initial collaboration, Dr. Gioia Massa, Veggie project scientist, connected with Rosenthal on a new grant proposal for upcoming Veggie experiments involving leafy greens and dwarf tomatoes.

CRF technologies

The NASA led team tested blending three different Florikan CRF technologies together to improve mizuna production. The three CRF technologies (Nutricote TM 18-6-8, Galxeone TM 14-4-14, YLD TM 0-0-19-9%, and 14-4-14) blended together provided the required results as each fertilizer technology released at different speeds resulting in healthy plants. The concept involves blending different CRF technologies to release plant nutrients at different speeds into one blend to grow mizuna mustard greens on the ISS.

Since 2015, Dr. Gioia Massa has led a research effort entitled: 'Pick-and-eat salad-crop productivity, nutritional value and acceptability to supplement the ISS food system' focused on developing a fresh food production capability on the ISS. The set of experiments used Veggie hardware to develop light and fertilizer combinations that would generate nutritious and attractive leafy green vegetables and dwarf tomatoes that astronauts can safely consume. This research will not only benefit astronauts on the ISS, it will also directly translate to Earth-based controlled environment production of these and similar crops in vertical farms and urban plant factories. The first two experiments with a leafy green crop, mizuna mustard, went ahead in 2019.

Figure 3. Astronaut Drew Morgan shows off his home grown mizuna on the International Space Station. *Photo Credit: NASA*

Historically, studies on edible food production in orbit have been limited, this new research fills some important gaps in studying the methods required to grow safe, acceptable, nutritious crops for consumption in microgravity. The Veggie vegetable-production system on the ISS offers an opportunity to develop a 'pick-and-eat' fresh vegetable component to the ISS food system as a first step to bioregenerative supplemental food production.

The goal is to grow salad crops in the Veggie unit during spaceflight and assess the impact of light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, organoleptic acceptability, nutritional value and behavioural health benefits. This work will help define light colour

Figure 4. Astronaut Jessica Meir enjoys her home grown mizuna salad on the ISS. *Photo Credit: NASA*

ratios, fertilizer composition and horticultural best practices to achieve high yields of safe, nutritious leafy greens and tomatoes to supplement a space diet of pre-packaged food. The final deliverable of this project will be to develop growth protocols for these crops in a spaceflight vegetable-production system. This will reduce the risk and close the gap of inadequate nutrition by helping NASA advance bioregenerative food production to supplement the packaged diet for future space exploration.

Multiple harvest cycles

The research was carried out in two parts (VEG-04A and VEG-04B) to test mizuna mustard under two different light quality treatments in space. The study also looked at the growth and sustainability of mizuna mustard plants for a long duration with multiple harvest cycles. Astronauts cared for the plants, documented plant development via photographs, harvested and weighed the plants before performing an organoleptic survey - a scientific taste test. During the course of the plant science experiment astronauts also filled out behavioural health surveys to assess how the plant growth activities impacted crew morale.

For experiment (VEG-04A), which was about a four week grow with a single harvest at the end, blends of controlled-release fertilizers were used in the following increments:

Florikan recommended 7.5 g/L Nutricote 18-6-8 T 70 blended with 5 g/L Nutricote 18-6-8 T 180 (total 12.5 g/L of dry substrate). Each plant pillow holds 250 mL of dry substrate Following testing and updating the watering protocol in between VEG-04 A and VEG-04 B, the fertilizer amounts were decreased slightly for the second test which was an eight week grow with two intermediate harvests from the plants culminating with a final harvest at the end. This cut-and-come-again experiment, VEG-04 B, used 4 g/L Nutricote 18-6-8 T 70 and 5 g/L Nutricote 18-6-8 T 180 mixed with the dry, granular arcillite.

Advancements in space crop production

The early collaboration between NASA and Florikan is an excellent example of how technologies can intersect and springboard to unanticipated advances in knowledge. NASA's expertise in polymer chemistry from the space shuttle programme advanced Florikan's knowledge to perfect their fertilizer product and enable efficient fertilizer application and reduce runoff fertilizer to bodies of water

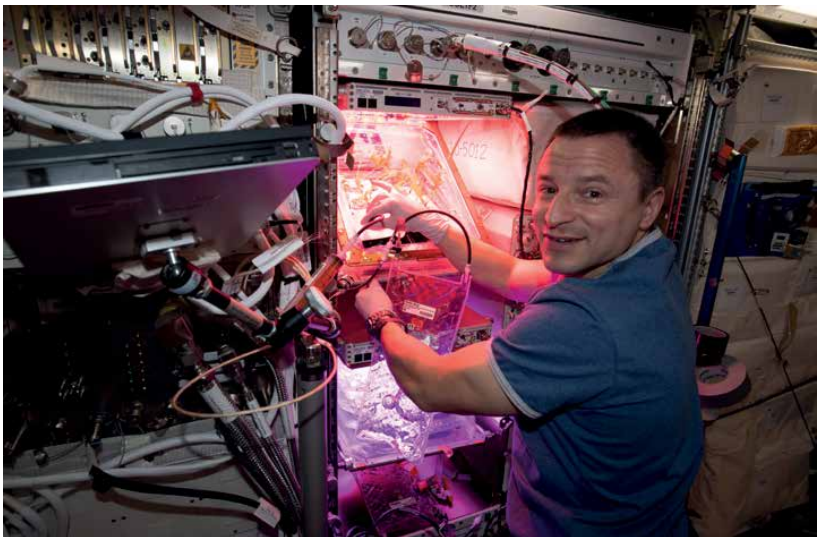

Figure 5. Astronaut Drew Morgan waters the mizuna garden growing in the Veggie facility on-board the International Space Station. *Photo Credit: NASA*

improving our planetary environment. Florikan's innovations with controlled release fertilizer products have been utilized by NASA's plant science researchers to grow crop plants in space to supplement astronaut diets with fresh, nutritious food. When the company perfected their controlled release fertilizer during the shuttle programme, no one at the time knew that those innovations would enable NASA's advancements in space crop production.

This story demonstrates the potential for meaningful collaboration between federal agencies and commercial industries and how early on NASA helped to accelerate the commercialization of a new product line. NASA's new T2X Programme is going back to its roots to do the same for startup companies building businesses around NASA technologies.

"Florikan has become the company that engineers encapsulated nutrients technology with the highest level of expertise and quality control," says Ed Rosenthal. "Much of this is due to the connection between Florikan and NASA, which has been a truly collaborative effort to develop a cutting edge CRF technology, NASA assisted us with coating development and product quality, and we, in turn have assisted NASA in finding a better way to grow veggies in space. This collaborative effort resulted in a joint induction into the Space Technology Hall of Fame by Florikan, NASA KSC and SATOP in 2017 (STHOF). Going forward, Eric Rosenthal, CEO and President, will continue the company's 40-year tradition of helping the growers 'find a better way'."

With NASA's Artemis Programme's efforts to land the first woman and next man on the Moon underway, NASA is developing innovative technologies to establish sustainable pathways to living, working and exploring in space. As scientists and engineers in the labs work tirelessly to make NASA's goals a reality, the Technology Transfer Programme (TTP) works simultaneously to evaluate, patent and transfer the technologies to the American public. Within NASA's TTP, the Technology Transfer Expansion T2X programme focuses specifically on encouraging startups to form around NASA technologies. These efforts by NASA aim to make stories like Florikan's the rule, not the exception. ■

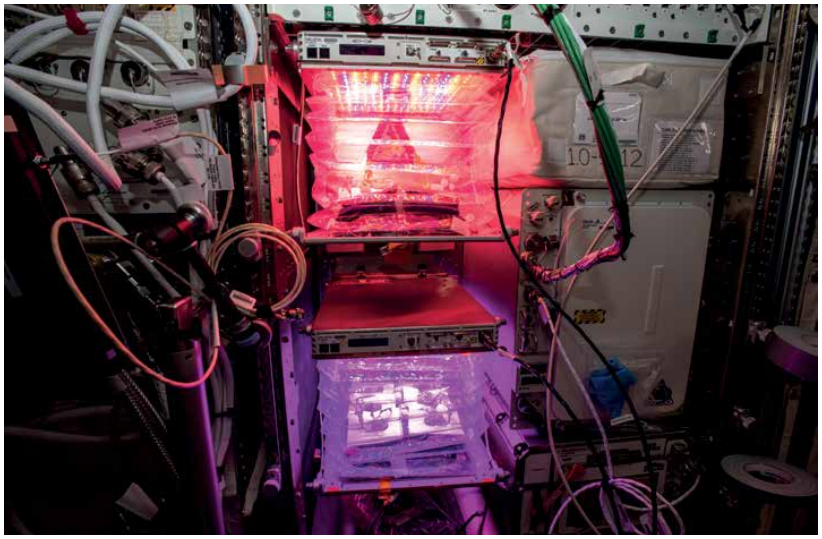

Figure 6. Mizuna plants growing inside the Veggie units on-board the ISS. *Photo Credit: NASA*

Figure 7. Astronauts on-board the International Space Station enjoy their home grown mizuna salad. *Photo Credit: NASA*

Trademarks cited:
Nutricote® is a registered trademark of JCAM Agri; Galxeone® is a registered trademark of JR Simplot; YLD® is a registered trademark of Florikan LLC