NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, US *(March 2024)*

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Impact Nugget:

The Advanced Plant Habitat (APH) and Veggie plant chambers continue to be used on the International Space Station (ISS). The APH controls PPFD up to 800 µmol m^{-2} s^{-1} using mixed LEDs, temperature, RH, CO_2, and soil water content. The Veggie uses LEDs with PPFD up to ~300-400 and draws cabin air through the chamber to provide cooling and CO_2, and hence has limited environmental control. Both chambers provide ~0.15-2.0 m^2 of growing area.

Fig. 1. *Left: Chile (chili) peppers growing in the Advanced Plant Habitat (APH) on the International Space Station (ISS). Right: Astronauts on ISS with chile peppers harvested from the APH chamber.*

Facility Description:

- Kennedy Space Center (KSC) has seven walk-in chambers and four reach-in chambers. Most chambers have T5 fluorescent lamps. We also use Heliospectra and OSRAM Phyofy LED fixtures inside the chambers. Sensor boxes for redundant temp, RH, and CO_2 monitoring are connected to Opto-22 modules along with custom software. Two walk-ins have CO_2 scrubbing systems using NaOH pellets. Larry Koss also built six smaller atmospherically closed chambers (ETCs) that can be placed inside larger walk-ins.

New Equipment / Sensors / Control Systems:

- We continue to use Heliospectra RX30 LED lighting systems for many of our studies. The fixtures provide nine, selectively dimmable LED wavelengths -- 380, 400, 420, 450, 520, 630, 660, 735 nm, and white (~5700 K). We also have 90 OSRAM PHYOFY RL lights 385, 450, 521, 660, 730 nm and white (2700 K). We have used single and multi-axis clinostats to simulate weightlessness in several chambers.
- Larry Koss of our team built six Environmental Test Chambers (ETC Chambers) that can be placed inside a walk-in chamber, allow for independent control of lighting, CO_2 and humidity. The interior dimensions of the chambers are: 40.6 cm x 45.7 cm x 48.3 cm (90 L).

Unique Plant Responses: Veggie VEG-05 tomato adventitious roots

During the Veggie tomato growth tests on ISS Dec. 2022-March 2023 we saw excess moisture leading to excessive adventitious root formation in 'Red Robin' dwarf tomatoes. Plants were grown in rooting pillows with porous ceramic substrate and controlled release fertilizer. An early low humidity event led to wicks drying and uneven germination. As plants became established, pillows were first manually watered by astronauts and then, starting at 45 days, fed by a root mat reservoir that wicked water to growing plants. Excess water seemed to wick around plant stems, perhaps causing plants to produce dense adventitious roots (Fig. 2).

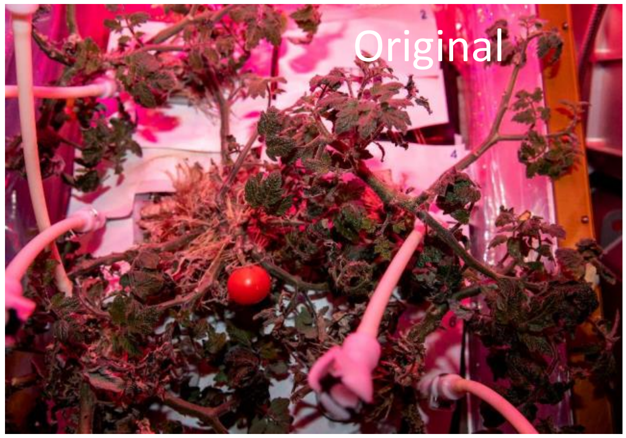

Fig. 2. *Adventitious roots grown in 'Red Robin' dwarf tomatoes grown on the ISS.*

Accomplishments:

- The VEG-05 test of dwarf tomatoes was conducted on ISS Dec. 2022-March 2023. A ground control ran through May 2023. Issues with low humidity led to drying and uneven germination and early growth. Later during growth and reproduction, plants received excess moisture, which led to flower and fruit loss. There were not enough fruit to allow astronauts to consume them, but ripe and unripe fruit along with leaf, adventitious root, and rooting pillow samples were frozen and returned to Earth for analysis.

- A test with the Advanced Plant Habitat (APH) on ISS finished in November 2021 growing cv. Espanola Improved chile (chili) peppers for 137 days. This was the longest single plant test in space to date. The crew consumed some fruit and completed surveys to assess the impacts of growing crops in space.

- As a part of collaboration between NASA and USDA (Epcot biotechnology laboratory), KSC tested plant growth promotion abilities of a fungus TC09 (*Cladosporium sphaerospermum*) on lettuce, mizuna and dwarf tomatoes in the ETCs. These chambers provided ability to assess TC09 effects under ambient and elevated CO_2 concentrations. We also did time-course transcriptome sequencing of the TC-09 fungus. Recently, we have acquired gene-edited tomato lines from Zach Lippman at the Cold Spring Harbor Labs for comparative testing with USDA ARS.

- We completed a 1-year study of 26 cvs. of pea and bean leading to 8 promising candidates for further study, nutritional and organoleptic analysis, and possible inclusion in future tests on ISS.

- LaShelle Spencer completed trials using various species grown to a micro-green harvest stage (~8-14 days) to support NASA's Human Research Program. To date, over 70 varieties of microgreens have been screened.

- Luke Fountain from Univ. of Sheffield joined the KSC team as a NASA Postdoctoral Fellow and is investigating the effects of elevated CO_2 on crop preference for different forms of nitrogen.

Impact Statements:

- KSC's space crop production research group has developed a list of knowledge gaps that has been vetted and approved with different NASA stakeholders. To enable partnership and collaboration on the challenges in controlled environment crop production we have been sharing our gaps list and having discussions with other government agencies, members of academia, and relevant industry professionals. The challenges that we face, while unique, have many intersections or areas of synergy with various sectors including agriculture automation and robotics, industrial sanitization, vertical farming, fluid and gas handling, modelling, sustainability and circular economy research, and greenhouse agriculture. Any NCERA-101 members interesting in our “gaps” list, please let us know. Ideas and edits are welcome!

Recent Publications:

Poulet et al. (2022) Large-scale crop production for the Moon and Mars: Current gaps and future perspectives. Front. Astron. Space Sci. 8:733944. doi: 10.3389/fspas.2021.733944

Stutte et al. 2022. Effect of reduced atmospheric pressure on growth and quality of two lettuce cultivars. Life Sci. Space Res. 34:37-44. https://doi.org/10.1016/j.lssr.2022.06.001

Hummerick et al. 2022. The Microbiology of Microgreens Grown in Controlled Environment Chambers under ISS Conditions. Intl. Conf. Environ. Systems ICES-2022-267

Schuerger et al (2022) Vegetable Health Challenges in Extraterrestrial Production. In: Elmer W.H., McGrath M., McGovern R.J. (eds) Handbook of Vegetable and Herb Diseases. Handbook of Plant Disease Management. Springer, Cham. https://doi.org/10.1007/978-3-030-35512-8_8-1

Teng et al. (2022). Microgreens for Home, Commercial, and Space Farming: A Comprehensive Update of the Most Recent Developments. Annual Reviews in Food Science and Technology. (in proofing)

Gott et al. (2022). Plasma sanitization of cherry belle radish seeds for Space agricultural applications. Plasma Res. Express, 4(2), 025001.

Meier et al.. (2021) Reviewing plasma peed treatments for advancing agriculture applications on Earth and into the final frontier. Gravitational and Space Research, 9(1), 133-158.

Hardy JM, Nabity JA, Kociolek P, Massa G. (2022) Review of Targeted Lighting Approaches for Controlled Environment Agriculture in Space Habitats. Intl. Conf. Environ. Systems ICES-2022-06

Morsi A, Massa GD, Morrow RC, Wheeler RM, Mitchell CA (2022) Comparison of two controlled-release fertilizer formulations for cut-and-come-again harvest yield and mineral content of Lactuca sativa L. cv. Outredgeous grown under International Space Station environmental conditions. Life Sci. Space Res. 32: 71-78 https://doi.org/10.1016/j.lssr.2021.12.001

Spencer, L., J. Gooden, A. Curry, T. Sirmons, R. Wheeler, M. Romeyn. 2023. Novel microgreen crop testing for space. Intl. Conf. on Environ. Systems ICES-2023-125.

Spencer et al. 2023. Legume crop testing for space. Intl. Conf. on Environ. Systems ICES-2023-124.

Wheeler. 2023. NASA’s contributions to vertical farming. Acta Hortic. 1369. ISHS 2023. DOI 10.17660/ActaHortic.2023.1369.1

Spencer et al. 2023. Novel microgreen crop testing for space. Intl. Conf. Environ. Systems. ICES-2023-125.

Spencer et al. 2023. Legume crop testing for space. Intl. Conf. Environ. Systems. ICES-2023-124

Morsi et al. 2024. Leaf yield and Mineral content of mizuna in response to cut-and-come-again harvest, substrate particle size, and fertilizer formulation in a simulated spaceflight environment. Life Sci. Space Res. https://doi.org/10.1016/j.lssr.2023.09.005

Wheeler et al.. 2024. Effects of elevated and super-elevated carbon dioxide on salad crops for space. J. Plant Interactions Vol. 19, No. 1, 2292219 https://doi.org/10.1080/17429145.2023.2292219

Bunchek et al. 2024. Pick-and-eat space crop production flight testing on the International Space Station. J. Plant Interactions, 19:1 https://DOI.org/10.1080/17429145.2023.2292220

Wang et al. 2024. Highly stretchable, robust, and resilient wearable electronics for remote, autonomous plant growth monitoring. Device 2, https://doi.org/10.1016/j.device.2024.100322

Scientific Outreach:

- The Growing Beyond Earth™ participatory science engagement program run by Fairchild Tropical Botanic Garden currently has over 450 middle and high schools conducting research and providing data to NASA, as the program completes its seventh year. Each participating school conducts science tests in a chamber mimicking the ISS Veggie chamber, and student scientists collect data on different types of plants and horticultural conditions. Projects in the 2023-2024 school year tested different types of leafy greens or herbs, irradiated seeds, competition in shared root zones, and dynamic LED lighting strategies for crop growth. .
- Since on-site work was reduced during COVID-19, our weekly seminar series for scientists and interns has gone virtual. This allows us to involve former interns and numerous external speakers.
- KSC food production team members continue to participate with university engineering design courses focused on aspects of space plant growth. University teams are helping to design or modify crop water delivery systems, robotic plant care systems, resource recovery systems, and more.