NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA *(September 2020)*

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Impact Nugget:

The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 5 years. Several crops of lettuce (cvs. Outredgeous, Waldmann's Green and Dragoon), Chinese cabbage (cv. Tokyo bekana), mizuna, 'Red Russian' kale, wasabi mustard greens, and pak choi (cv. Extra Dwarf) have been grown and the astronauts were allowed to eat the leaves for many of these experiments. The passive, capillary-based watering system has not worked reliably and the astronauts have been watering manually. A new watering systems called PONDS had challenges in initial testing, but a modified PONDS will be tested soon. The PONDS system involves a plastic water reservoir with a cylinder of wetting and non-wetting solid media placed in the center of the reservoir. Water is delivered to the solid media with a series of wicks sticking into the water.

Facility Description:

- Kennedy Space Center (KSC) currently has six Percival walk-in chambers (6 ft X 8 ft) and four reach-in chambers for the Space Station Processing Facility (SSPF), and we continue to organize a nearby lab for storing plant and chamber supplies, and planting and harvesting activities. All chambers have T5 fluorescent lamp banks with supplemental incandescent sockets. Larry Koss of our team installed aspirated sensor boxes for redundant temperature, RH, and CO_2 monitoring, and has connected them all to Opto-22 modules along with a custom developed software systems for real-time, graphic output with a computer in the growth chamber area for all the walk-in chambers and will continue this with the reach-in chambers. Alarming for power failures and lighting have been implemented and irrigation alarms will be implemented soon. The Opto-22 system can also accommodate additional sensor and control functions, such as irrigation timing or pH and EC for hydroponic systems. In addition, we installed two CO_2 scrubbing systems that support trays of NaOH pellets. We have found that these scrubbers can hold ambient ~400 ppm CO_2 while one person is inside the chamber, but require regular checking of the color-indicating NaOH pellets.

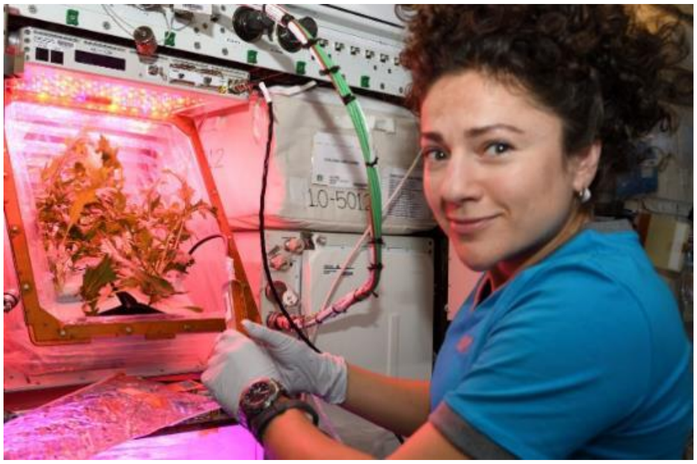

Fig. 1. *Jessica Meir with mizuna plants in Veggie on the International Space Station Oct 2019. .*

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 use four dimmable, 6500 K white LED arrays from BIOS Lighting (Melbourne, FL) and six red-green-blue BPSe arrays from SNC-ORBITEC (Madison, WI) mimicking the Veggie hardware. We also have purchased 50 OSRAM PHYOFY RL lights to outfit several of our growth chambers and plant growth rooms, with the intent of eventual replacing the Heliospectra RX30 lighting fixtures. The OSRAM Phytofy RL has selectively dimmable

LED wavelengths at 385, 450, 521, 660, 730 nm and white (2700K). We have installed a vertical wall growing system in one of our chambers that contains the 6 BPSe lights as well as 6 OSRAM PHYTOFY lights in 9 growth spaces for crop testing under environmental conditions relevant to the International Space Station.

Unique Plant Responses:

- We completed a series of tests to grow different leafy crops in controlled environments with or without supplemental far-red lighting. These included chard, wasabi mustard, amara mustard, shungiku (an edible crysanthemum), several radicchio spp., several escaroles, sorrel, pak choi, red mustard, kale, red Russian kale, as well as lettuce. In general, species with distinct stems and internodes showed more elongation with supplemental FR (as expected), while heading plants (lettuce, escarole, radicchios) showed greater leaf expansion with FR. The Pak Choi cv. Extra Dwarf showed no difference.

Accomplishments:

- Ye Zhang and Matt Romeyn continued to oversee some of the "validation" testing with Veggie plant growth systems on the International Space Station (ISS), which mixed crop tests with two types of lettuce and mizuna, continuous production in two veggie units, and the addition of new crops, Red Russian Kale, Dragoon lettuce, Wasabi mustard, Amara mustard and Extra Dwarf pak choi. Additionally, a seed film delivery technology will be tested in the upcoming Veg-03J technical demonstration test.

- A technical demonstration in the Advanced Plant Habitat (APH) on ISS is slated to launch in early 2021 that will grow cv. Espanola Improved chili peppers for a period of 120 days. This test will assess the capabilities of APH to conduct long-duration plant growth operations and the nutritional and microbiological differences that arise in chili peppers grown in microgravity. This project is being conducted by Matt Romeyn, LaShelle Spencer, Oscar Monje, Jacob Torres, Jeff Richards, and Nicole Dufour.

- Gioia Massa has a 3-yr NASA grant to conduct the first official plant testing using Veggie (with leafy greens in 2019 and dwarf tomato in 2022). Ray Wheeler, Mary Hummerick, Matt Romeyn, LaShelle Spencer, and Jess Bunchek at KSC, Bob Morrow at Sierra Nevada, and Cary Mitchell at Purdue are Co-Is on the grant along with several Co-Is from Johnson Space Center focusing on food and behavioral health. The focus of this research is to assess fertilizer and light quality impacts on crop growth, nutrient content, and organoleptic appeal. We have worked closed with Florikan Inc. to assess different controlled release (CR) fertilizer combinations. Two sets of mizuna were grown in Veggie plant pillows, one for 35 days and the second for 60 days with repetitive harvesting under both red-rich (ratio of 9:1:1 Red: Blue: Green) and blue-rich (ratio of 5:5:1 Red: Blue: Green) LED light. Tomatoes will be grown in the Veggie using the Passive Orbital Nutrient Delivery (PONDS) growing system under the same lighting conditions to complete the project. A modified version of the PONDS hardware will be tested on ISS soon.

- Mary Hummerick and LaShelle Spencer along with super undergraduate and graduate interns, conducted several tests with lettuce, mizuna, radish, dwarf tomato and dwarf peppers to assess their microbial counts, and compared these to similar vegetables purchases in local grocery stores. The intent of these studies was to establish some baseline or "norm" for acceptable microbial counts and food safety for space crops. In general, plants grown in the controlled environment chambers were lower in microbial counts than similar crops purchased at grocery stores, and in all cases, the levels of microbes could be reduced by treating the leaves or fruits with ProSan, a citrate based sanitizing agent. Colleagues at Johnson Space Center have used the data to develop a risk assessment for fresh produce grown in space.

- LaShelle Spencer, Matt Romeyn, Ray Wheeler and some super interns completed a set of studies where leaf vegetables were grown at 400, 1500, 3000, and 6000 ppm CO_2 to study growth and development, and stomatal conductance across a range of CO_2. For the first tests at 400, it became very difficult to hold the set point due to CO_2 pollution in the surrounding room and humans coming and going in the chamber. We later added CO_2 scrubbing systems from Percival, which contain multiple trays with color-indicating NaOH coated pellets. This worked quite well for holding 400, even with one person in the chamber. But you need to be sure the pellets are changed when they are exhausted. Larry Koss of the KSC group put a clear acrylic "window" on the scrubbing box to allow easy viewing of the pellets.

- A two year tomato and pepper screening study was completed, with over 40 cultivars being screened and promising candidates down-selected for further growth studies and nutritional and organoleptic analysis.

- A one year study to screen microgreen cultivars was finished in 2020. This is the first of several projects aimed at identifying promising microgreen species / cultivars for use in space and assessing nutritional impact and food safety. KSC has brought on a new postdoc and partnered with USDA ARS in Beltsville, MD to develop microgreens as a future crop for spaceflight.

- Studies on herbs were initiated to consider what herb varieties might be best for supplementation of packaged diets in space flight. Sixteen herb varieties were tested initially in spring of 2020, and this work will continue with down selection based on growth, and nutrient content. Additionally, upcoming studies will focus on herbs that will grow well as microgreens.

- Lucie Poulet was selected as a NASA Postdoctoral Fellow and began working at KSC in January, 2019, on a project entitled "Modeling plant growth and gas exchanges in various ventilation and gravity levels." Lucie has been using the LI-6800 to study plant leaf responses to different ventilation levels and has designed a custom chamber for the LI-6800 which will allow similar studies of entire crop plants and canopies of microgreens. Data collected will be used to calibrate and validate a plant gas exchange model in reduced gravity environments.

- Christina Johnson was selected as a NASA Postdoctoral Fellow and began working at KSC in August 2019 with a focus on microgreens. She has been assessing the differences between microgreens grown in unit gravity versus those grown in simulated microgravity via clinostats and random positioning machines. She is working with a team to design a microgreens growth and imaging platform that will be used on a random positioning machine and enable testing of microgreens growth responses to different simulated gravity levels including lunar and Martian gravity. Christina leads monthly Microgreen Chats where she brings together contacts from NASA, USDA, academia, and the private sector with interest in microgreens.

Fig. 2. *Herb evaluation utilizing OSRAM Phytofy LED fixtures.*

Impact Statements:

- KSC's space crop production research group has developed a list of 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.

Fig. 3. *Left: Test of leafy greens as candidate spaceflight crops. Tests were carried out at 400, 1500, 3000, and 6000 ppm CO_2 to straddle a range of CO_2 levels that might be encountered in space craft like the Intl. Space Station. Right: Heliospectra RX 30 LEDs fixtures used for lighting in the studies.*

Recent Publications:

Asseng, S., J.R. Guarin, M. Raman, O. Monje, G. Kiss, D.D. Despommiere, F.M. Meggers, and P.P.G. Gauthier. 2020. Wheat yield potential in controlled-environment vertical farms. Proc. Natl. Acad. of Sci. www.pnas.org/cgi/doi/10.1073/pnas.2002655117 .

Burgner, S.E., C. Mitchell, G. Massa, M.W. Romeyn, R.M. Wheeler and R. Morrow. 2019. Trouble-shooting performance failures of Chinese cabbage for Veggie on the ISS. 49th Int. Conf. on Environ. Systems, ICES-2019-328.

Burgner, S.E., K. Nemalia, G.D. Massa, R.M. Wheeler, R.C. Morrow, C.A. Mitchell. 2020. Growth and photosynthetic responses of Chinese cabbage (*Brassica rapa* L. cv. Tokyo Bekana) to continuously elevated carbon dioxide in a simulated Space Station "Veggie" crop-production environment. Life Sci. Space Res. 27:83-88, https://doi.org/10.1016/j.lssr.2020.07.007

Douglas GL, Massa GD, Hummerick ME, Hinze PE (2020) Cold plasma to disinfect spaceflight grown produce. In Advances in Cold Plasma Applications for Food Safety and Preservation, Ed. Daniela Bermudez-Aguirre. Pages 333-340. https://doi.org/10.1016/B978-0-12-814921-8.00012-8

Dreschel, T.D., W.M. Knott, R.P. Prince, J.C. Sager, and R.M. Wheeler. 2019. From Project Mercury to the Breadboard Project. 49th Int. Conf. on Environ. Systems, ICES-2019-106.

Graham, T., N. Yorio, P. Zhang, G. Massa, and R. Wheeler. 2019. Early seedling response of six candidate crop species to increasing levels of blue light. Life Sci. Space Res. 21: 40–48.

Hardy, J.M., P. Kusuma, B. Bugbee, R. Wheeler, and M. Ewert. 2020. Providing photons for food in regenerative life support: A comparative analysis of solar fiber optic and electric light systems. 2020 International Conference on Environmental Systems, ICES 2020-07-523.

Khodadad C.L., M, E. Hummerick, L.E. Spencer, A.R. Dixit, J.T. Richards, M.W. Romeyn, T.M. Smith, R.M. Wheeler, and G.D. Massa. 2020. Microbiological and nutritional analysis of lettuce crops grown on the International Space Station. Front. Plant Sci. 11:199.doi: 10.3389/fpls.2020.00199.

Monje, O., M.R. Nugent, M.E. Hummerick, T.W. Dreschel, L.E. Spencer, M.W. Romeyn, G.D. Massa, R.M. Wheeler, and R.F. Fritsche. 2019. New frontiers in food production beyond LEO. 49th Int. Conf. on Environ. Systems, ICES-2019-260.

Monje O., J.T. Richards, J.A. Carver, D.I. Dimapilis, H.G. Levine, N.F. Dufour and B.G. Onate. 2020. Hardware validation of the Advanced Plant Habitat on ISS: Canopy photosynthesis in reduced gravity. Front. Plant Sci. 11:673. doi: 10.3389/fpls.2020.00673 .

Poulet, L., M. Gildersleeve, L. Koss, G.D. Massa, R.M. Wheeler. 2020. Development of a photosynthesis measurement chamber under different airspeeds for applications in future space crop-production facilities 2020 International Conference on Environmental Systems, ICES 2020-07-077.

Romeyn, M.W., L.E. Spencer, G.D. Massa, and R.M. Wheeler. 2019. Crop readiness level (CRL): A scale to track progression of crop testing for space. 49th Int. Conf. on Environ. Systems, ICES-2019-342.

Spencer, L.E., M.E. Hummerick, G.W. Stutte, T. Sirmons, G. T. Graham, G. Massa, and R.M. Wheeler. 2019. Dwarf tomato and pepper cultivars for space crops. 2019. 49th Int. Conf. on Environ. Systems, ICES-2019-164.

Spencer, L. R. Wheeler, M. Romeyn, G. Massa, M. Mickens. 2020. Effects of supplemental far-red light on leafy green crops for space. 2020 International Conference on Environmental Systems, ICES 2020-07-380.

Wheeler R.M., A.H. Fitzpatrick and T.W. Tibbitts. 2019. Potatoes as a crop for space life support: Effect of CO_2, irradiance, and photoperiod on leaf photosynthesis and stomatal conductance. Front. Plant Sci. 10:1632. doi: 10.3389/fpls.2019.01632

Scientific Outreach:

- The "Growing Beyond Earth" educational collaboration with Fairchild Tropical Botanic Gardens in Miami continues to generate data for NASA, while inspiring middle and high school students. Students, first in south Florida and now around the country have botany racks in their classrooms with LED lights and are helping to select crops and define growing techniques for space. They post their progress and results on twitter @growbeyondearth and provide their data to NASA. Building on the success of this citizen-science initiative, Fairchild has also been awarded additional grants to develop the first ever maker space in a botanical garden, the Growing Beyond Earth Innovation studio, which hosted the first year of the Growing Beyond Earth Maker challenge to professional, university, and high school makers in 2019-2020, and is now starting the second year of this maker challenge.

- KSC continues to average 3-5 undergraduate and graduate students as food production interns in summer, fall, and spring terms, except during a reduction of onsite work during COVID-19. Interns work on plant growth experiments, hardware development and testing, and space food production strategic planning. Currently we have one virtual intern conducting work remotely on bioinformatics and supporting Christina Johnson's work.
- Since on-site work was reduced our weekly seminar series for scientists and interns has gone virtual. This has allowed us to involve former interns and invite presentations from numerous external speakers.
- KSC food production team members continue to advise universities in 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 many other types of space plant production hardware.
- Ray Wheeler owed Ted Tibbitts a paper on some of their potato research since ca. 1988. Ray finally around to getting it published, only `30 years late. The ambient, control [CO_2] at the time was 350 ppm!

Committees / Panels:

ASHS CE Working Group (Wheeler)
Com. on Space Research (COSPAR) Sub-Commission F4.2 Chair (Wheeler)
EDEN-ISS Project (EU Funded) Science Advisory Board (Wheeler)
Amer. Soc. Grav. and Space Res. (ASGSR) Governing Board and Education / Outreach Committee (Massa)
CEA Food Safety Coalition Advisory Council (Massa, Hummerick)