NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (Sept 2016)

Gioia Massa, Gary Stutte, LaShelle Spencer, Tom Graham, Matthew Mickens, Ray Wheeler

Impact Nugget:

The Veggie vegetable production system has been operating on the International Space Station (ISS) for more than 2 years. The passive, capillary based watering systems is still causing some issues (some rooting pillow packets did not get sufficient water). But a second crop of red romaine lettuce plants was grown and the crew members of the ISS were allowed to eat the leaves—a first for NASA astronauts. The most recent use of Veggie was to let the astronauts do their own "gardening" in space, and a photo of some space-grown zinnia flowers in front of the space station cupola window is shown in Fig. 1.

Figure 1. Zinnia flowers grown in Veggie on the International Space Station (ISS). The Earth is in the background of the cupola window in the ISS.

Facility Description:

We continued to rent several walk-in and reach-in chambers at Space Life Sciences Lab (SLSL), and in addition have been using two reach-in chambers with red-blue LED lamp fixtures at the SSPF building at Kennedy Space Center. Larry Koss, our electro-mechanical lead has nearly completed a retrofit of a large Thermotron walk-in chamber for growing plants in O&C Building on the main campus of Kennedy Space Center. Larry added banks of T8 fluorescent lamps and has set up his Opto-22 based monitoring and control system. The compressor needed to be repaired, which was just completed so we're anxious to try it out. A plant processing area has been established in the SSPF building as well.

New Equipment / Sensors / Control Systems:

- We purchased a Decagon SC-1 porometer for stomatal conductance measurements. It is much smaller than our Li-Cor steady state porometer, and has a built in data logger. Additional equipment purchased in the establishment of the plant processing area includes a large capacity Thermo Scientific forced air oven, a Gilson sieve shaker with sieves for sorting substrate particle sizes, a Wiley tissue mill, a Li-Cor LI-3100C leaf area meter, and Li-Cor quantum meters, an Apogee spectroradiometer, an Atago portable refractometer, a Minolta SPAD meter, a FLIR C2- pocket sized thermal Imaging system, a Heliospectra RX30 lamp, and other standard analytical equipment. ORBITEC retrofitted 6 Biomass Production Systems for Education (BPSe) with LED light-caps to mimic the Veggie system.

Unique Plant Responses:

- We continue to grow, propagate, and pollinate genetically engineered plum (*Prunus domestica)* trees with overexpressed FT1 flowering gene (developed by the ARS at Kearneysville, WV). The plants do not have any cold-period dormancy requirements for flowering, which is an advantage as a potential space crop. We have been able to grow fruit from the several of the lines, but have been fighting thrips in these studies, which is new challenge for our growth chamber testing. We are also in early talks with the USDA and other university collaborators to explore tissue specific GA oxidase expression to further reduce the volume requirements for these plants.

Accomplishments:

- Gioia Massa oversaw the "validation" testing with Veggie plant growth systems on the International Space Station (ISS) last spring. Veggie has come a long way from Bob Morrow's back of the envelope concepts in the mid-1990s to actually growing plants (red romaine lettuce) on the ISS in 2014! Veggie crop varieties of red romaine lettuce and Chinese cabbage were planted in the White House Kitchen Garden becoming part of a tradition the First Lady began in 2009 to inspire children to develop healthier eating habits. Gioia also received a 3-yr NASA grant to conduct the first official plant testing with Veggie (with leafy greens and dwarf tomato). Ray Wheeler and Mary Hummerick at KSC, Bob Morrow at ORBITEC, and Cary Mitchell at Purdue are co-Is on the grant along with other Co-Is from Johnson Space Center focusing on food and behavioral health. Matt Romeyn at KSC is a new scientist with our group who has been running the ground studies as we prepare for flight.

- We completed a series of tests to compare dwarf tomato and pepper varieties as possible space crops, and LaShelle Spencer and Mary Hummerick deserve much of the credit for this work. Fruits from the various cultivars were sent to NASA Johnson Space Center for sensory evaluation (taste testing). The overall winners were cv. Red Robin tomato and cv. Pompeii pepper (Fig. 3).

- Ani Dixit in our group completed his testing with *Arabidopsis* plants grown under elevated and super-elevated CO_2 (400, 1500, 4000 and 8000 ppm). Transcriptome analysis of the plants showed the various secondary metabolites, including lignin related genes, are up-regulated in plants grown for 30 days at super-elevated CO_2. We are still pondering these findings.

- Tom Graham completed a series of red-blue spectral quality tests with seedlings of tomato, pepper, soybean, cucumber, snow pea, and radish. Like many others in NCERA-101, we are seeing a general effect of reduced stem or hypocotyl growth with more blue in the spectrum. But similar to our stalwart colleagues, Ricardo Hernandez and Chieri Kubota, we saw a peculiar increase in elongation under pure blue (~450 nm) light. In looking back through John Sager's phytochrome photostationary state papers, we think some species see the pure blue light as a "farred" like source, even though cryptochrome signals are likely saturated.

- Matt Mickens has initiated growth comparisons of lettuce, and under white LEDs supplemented with red (635 nm), blue (460 nm), green (525 nm), and farred (745 nm) LEDs. A sixth treatment is using a Heliospectra light fixture with LEDs at 425, 525, 660, and 733 nm. The white LEDs are about 2800 K color temp. Next year's report should have full results. An invaluable member of the team was our summer intern Emilie Skoog from USC. If that name looks familiar, yes, Folke was one of her relatives!

Impact Statements:

- Thanks to many hard working colleagues at KSC, ORBITEC, and numerous universities, the plant controlled environment and CEA community have successfully extended their reach to the International Space Station with the Veggie plant growth unit. NASA and ORBITEC are planning to build an even larger (0.2 m^2), more highly controlled plant research chamber called the Advanced Plant Habitat, or APH. Hopefully we can keep the momentum.

Figure 3: Dwarf FT overexpressed plum tree about 12 months from rooting with flowers.

Figure 2. Dwarf tomato (cv. Red Robin) grown in studies to assess cultivars for possible use in space.

Recent Publications/Presentations:

Massa, G.D., Wheeler, R.M., Morrow, R.C., Levine, H.G. 2016. Growth chambers on the International Space Station for large plants. Acta Hortic. 1134: 215-222. DOI: 10.17660/ActaHortic.2016.1134.29

Graham, T., R. Scorza, R. Wheeler, C. Dardick, B. Smith, A. Dixit, D. Raines, A. Callahan, C. Srinivasan, L. Spencer, J. Richards, G. Stutte. 2015. Over expression of FT1 in plum (*Prunus domestica*) results in phenotypes compatible with spaceflight: A new candidate crop for bioregenerative life-support systems? Gravitational and Space Research 3 (1): 39-50.

Graham, T., R. Wheeler, R. Scorza, C. Dardick, A. Callahan, D. Raines, A. Dixit, A.L. Paul, B. Smith, G. Stutte, L. Spencer, R. Ferl, C. Srinivasan, G. Massa, J. Richards. 2015. Trees in Space: No longer the forbidden fruit. Amer. Assoc. Gravitational Space Res. Ann. Conf., Alexandria VA, November 10-15, 2015.

Graham, T., R. Wheeler, R. Scorza, G. Stutte, C. Dardick, A. Callahan, B. Smith, R. Barker, A. Dixit, L. Spencer. Space orchards: No longer the forbidden fruit. The making of spaceflight compatible fruit trees. 7th AgroSpace Intl. Workshop, Sperlonga, Italy. May 26-27, 2016.

Graham, T., and Ray Wheeler. Revisiting mechanical plant dwarfing mechanisms for improving volume utilization efficiency in spaceflight plant production systems. Amer. Assoc. Gravitational Space Res. Ann. Conf. Alexandria, VA, November 10-15, 2015.

Massa, G.D., T. Graham, T. Haire, C. Flemming, G. Newsham, and R. Wheeler. 2015. Light-emitting diode light transmission through leaf tissue of seven different crops. HortScience 50(3):501–506.

Massa, G.D., E. Chase, J.B. Satini, and C.A. Mitchell. 2015. Temperature affects long-term productivity and quality attributes of day-neutral strawberry for a space life-support system. Life Sciences in Space Research 5:39-46.

Massa, G.D., R.M. Wheeler, G.W. Stutte, J.T. Richards, L.E. Spencer, M.E. Hummerick, G.L. Douglas, and T. Sirmons. 2015. Selection of leafy green vegetables varieties for a pick-and-eat diet supplement on ISS. 45th Intl. Conf. on Environ. Systems, ICES-2015-252.

Massa, G.D. and J. Norrie. 2015. LEDs electrifying horticultural science: Proceedings form the 2014 colloquium and workshop. HortScience 50(9):1272- 1273.

Morrow, R.C. R.C. Richter, G. Tellez, O. Monje, R. Wheeler, G. Massa, N. Dufour, and B. Onate. 2016. A new plant habitat facility for the ISS. Intl. Conf. on Environmental Systems, ICES-2016-320.

O'Keefe, C.M., G.W. Stutte and M. McKeon-Bennett. 2015. Ragwort: Invasive weed and potential pharmaceutical. In: J. Janick, (*ed*.), Horticultural Reviews 43:145-178.

Stutte, G.W., O.A. Monje, R.M. Wheeler. 2015. A. Rai and N. Hosein (*eds*). A Researcher's Guide to International Space Station Plant Science. NASA NP-2015-03-014-JSC, 47 pages.
Stutte, G.W. 2015. Commercial transition to LEDs: A pathway to high-value products. HortScience 50(9):1297-1300.

Scientific Outreach:

- In collaboration with Fairchild Tropical Botanic Gardens in Miami, a school challenge was developed, which enabled 124 schools and more than 3000 middle and high school students in south Florida to have botany racks installed in their classrooms with LED lights. Students researched and grew multiple crop varieties to help select new crops that could eventually be grown in the Veggie hardware on ISS and they posted their progress and results on twitter. Fairchild Gardens plans to continue and expand this program with help from a NASA grant to informal learning institutes that they were awarded.

Committees / Panels:

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