NCERA-101 STATION REPORT FROM KENNEDY SPACE CENTER, FL, USA (April 2009)

Impact Nugget:

Concentration of the bioprotective anthocyanin pigments were increased four fold in lettuce cv. Outregeous grown under red LEDs through selective application of blue light.

Facility Description:

The Space Life Sciences Lab (SLSL) Controlled Environment Lab (CEL) has been operational for 5 ½ years and provides 606+ ft^2 (56 m^2) of controlled environment chamber space. The CEL provides support to both basic and applied research with emphasis on ground-based and space applications. Redundant to local chamber environmental control, the laboratory has developed and maintained a centralized command, monitoring, and data system (CMDS) with an associated database and alarming capabilities. The CEL is used to support the requirements of a variety of scientific research areas including NASA, private industry, and academia.

New Equipment / Sensors / Control Systems:

- The primary control and monitoring system for the CEL, CMDS [Command, Monitoring and Data System], continues to improve with added capabilities including remote access via internet, alarming, and data collection and analysis. The flexibility of CMDS allows for development to meet user or project specific requirements.
- An EGC M-48 chamber was modified to have zero-humidity air input (via facility installed desiccant dryer) as a method of dropping chamber relative humidities to < 10%. The desiccant drier also absorbs CO_2, thus allowing for the possibility to easily perform sub-ambient (~ 100 ppm) CO_2 studies.
- Recently added a 2 m^2 solar light concentrator to the roof of the SLS Lab. This system was developed as a NASA phase II small business innovative research (SBIR) grant to Physical Sciences, Inc. and is intended for a plant growth lighting application. Primary collection mirrors focus solar radiation on secondary cold mirrors (transparent to long wave radiation), which then focus the visible radiation onto an inlet fiber optic bundle. The radiation is transported via fiber optics into a modified EGC GC-36 chamber to irradiate ~ 1 m^2 with PAR equivalent to full sunlight.
- Continued testing and use of a new high output LED array from ORBITEC with $\geq$300 μmol m^{-2} s^{-1} PPF @ each of six wavelengths (400, 440, 520, 640, 660, and 730 nm).
- A Low Pressure Tesbed (LPT) was recently added which provides a capability for maintaining atmospheric pressure, temperature, and relative humidity for a variety of testing applications.
- A vacuum chamber for lunar and Mars dust/regolith testing has been installed with 10^{-7} Torr capability.
- LADA plant growth units similar to those being used in the Russian module of the International Space Station were tested in an EGC M-12 chamber to assess microbial communities on radish roots for food safety.
- ORBITEC has delivered two "VEGGIE" units (Phase II SBIR grant from NASA) as a deployable plant growth system for producing salad type crops. The VEGGIE design provides growing areas that can be "daisy chained" together to provide approximately a 1 m^2 growing area (6 VEGGIE units) and can be stowed within a single crew transfer bag on the Space Shuttle. The VEGGIE units provide LED lighting and a water/nutrient delivery matting, but utilize the cabin environment for temperature and CO_2 control to minimize complexity and power requirements.
- Continued development of a "Lighting Testbed" with the addition of a 1-m integrating sphere and an Optronics spectroradiometer with spectral range in the visible and near IR (380 to 1180 nm) to obtain spectral power distributions and total lumen outputs as well as a goniometer to obtain lamp distribution characteristics.

Unique Plant Responses:

- Anthocyanin production in red leaf lettuce (cv. Outredgeous) grown under red (640 nm) LEDs was shown to be dependent upon blue light exposure. Blue light at 440 nm was more effective than 400 nm at inducing anthocyaninin production. Anthocyanin production in lettuce grown under red (640 nm) LEDS was greatly enhanced with application of UVB radiation, but not UVA. Differences were observed between two red leaf lettuce cultivars (Outredgeous and Firecracker) on anthocyanin production grown under triphosphor fluorescent lamps with UV transmitting barriers.
- Growth of two lettuce cultivars (Outredgeous and Flandria) were reduced when grown under hypobaric conditions of 33 kPa compared to 66 or 98 kPa (control). This contrasts with prior results showing no effect of hypobaria on growth and yield of radish, cv. Cherry Bomb II Hybrid.

Accomplishments:

- Completed series of experiments to increase the bioprotective value of red leaf lettuce grown under LEDs under conditions that were relevant to long duration space missions. Bioprotective properties can be significantly enhanced without increases in volume, power or mass inputs through the selective use of LED lighting systems.
- Completed a set of experiments in collaboration with the University of Guelph to study the effects of reduced pressure on the growth, development, and secondary metabolite levels in two cvs. of lettuce. Plants were grown for 21 days at 1/3 (33 kPa), 2/3 (67 kPa) and ~3/3 (98 kPa) atm with constant pO_2 of 21 kPa.

- Initiated a series of experiments to demonstrate sustained production of lettuce and radish in prototype "Salad machine" modules in order to identify issues associated with plant production on a lunar base. Two prototype plant growth units "VEGGIE" and "BPSe" developed by ORBITEC are being used for these experiments.
- Fully characterized Solid State Lighting Module (SSLM) as well as three other commercial of the shelf (COTS) luminaires on the following parameters: photopic luminous flux, scotopic luminous flux, color rendering index, correlated color temperature, total radiant power, radiant efficiency, luminous efficacy, color coordinates in four different color spaces, color gamut area, power spectral distribution, light distribution profile, photosynthetic active radiation (PAR), photosynthetic photon flux (PPF), and phytochrome photostationary state.

Impact Statements:

- NASA KSC conducted baseline experiments to quantify the effects of hypobaric conditions on the growth, productivity, and bioprotective potential of lettuce cultivars being considered for long-duration space missions. Results suggested that hypobaric conditions of 33 kPa may have detrimental impact of biomass production.
- NASA KSC has demonstrated that the bioprotective value of salad crops, which have potential as a biological countermeasure to radiation on long-duration space missions, can be significantly increased by the selective use of LEDs to regulate plant morphology and anthocyanin synthesis.
- NASA KSC has initiated experiments to evaluate the continuous production of salad crops using realistic environmental constraints on a Lunar outpost. Several issues associated with maintaining soil water content, environmental control, and mission operations have been identified and addressed.

Recent Publications/Presentations:

Drysdale, A., T. Nakamura, N. Yorio, J. Sager, and R. Wheeler. 2008. Use of sunlight for plant lighting in a bioregenerative life support system--Equivalent system mass calculations. Adv. Space Res. 42:1929-1943.

Levine, L.H., P.A. Bisbee, T.A. Richards, M.N. Birmele, R.L. Prior, M. Perchonok, M. Dixon, N.C. Yorio, G.W. Stutte, and R.M. Wheeler. 2008. Quality characteristics of radish grown under reduced atmospheric pressure. Adv. Space Res. 41:754-762.

Levine, L.H., H. Kasahara, J. Kopka, A. Erban, I. Fehrl, F. Kaplan, W. Zhao, R.C. Littell, C. Guy, R. Wheeler, J. Sager, A. Mills, and H.G. Levine. 2008. Physiologic and metabolic responses of wheat seedlings to elevated and super-elevated carbon dioxide. Adv. Space Res. 42:1917-1928.

Massa, G.D, H.H. Kim, R.M. Wheeler, and C.A. Mitchell 2008. Plant productivity in response to LED lighting. HortScience 43(7): 1951-1956.

Mortley, D.G., C.K. Bonsi, W.A. Hill, C. Morris, C.S. Williams, C.F. Davis, J.W. Williams, L.H. Levine, B.V. Petersen and R.M. Wheeler. 2008. Influence of microgravity environment on root growth, soluble sugars, and starch concentration of sweetpotato stem cuttings. J. Amer. Soc. Hort. Sci. 133:327-332.

Nakamura, T., A.D Van Pelt, N.C. Yorio, A.E. Drysdale, R.M. Wheeler, and J.C. Sager. (2009) Transmission and distribution of photosynthetically active radiation (PAR) from solar and electric light sources. Habitation (in press).

Stutte, G.W., I. Eraso and A.M Rimando. 2008. Carbon dioxide enrichment enhances growth and flavonoid content of two Scutellaria species. J. Amer. Soc. Hort. Sci. 133: 631-638.

Stutte, G.W., S. Edney and T. Skerritt. 2009. Photoregulation of bioprotectant content of red leaf lettuce with light emitting diodes. HortScience 44: 79-82.

Stutte, G.W. 2009. Light emitting diodes for manipulating the phytochrome apparatus. HortScience 44: (in press)

Takeda, F., D. M. Glenn and G.W. Stutte. 2008. Red light affects flowering under long days in a short-day strawberry cultivar. HortScience 43: 2245-2247.

Wheeler, R.M. 2008. A historical background of plant lighting. HortScience 43(7):1942-1943.

Wheeler, R.M., C.L. Mackowiak, G.W. Stutte, N.C. Yorio, L.M. Ruffe, J.C. Sager, R.P. Prince, and W.M. Knott. 2008. Crop productivities and radiation use efficiencies for bioregenerative life support. Adv. Space Res. 41:706-713.

Wheeler, R.M., G.W. Stutte, C.L. Mackowiak, N.C. Yorio, J.C. Sager, and W.M. Knott. 2008. Gas exchange rates of potato stands for bioregenerative life support. Adv. Space Res. 41:798-806.

Scientific Outreach:

Committees / Panels:

ASHS CE Working Group (Stutte, Yorio, Wheeler)
Intl. Advanced Life Support Working Group (Wheeler)
Com. on Space Research (COSPAR) F4 (Wheeler)
ASABE Board of Trustees (Sager)

Visiting Scientists:

Peter Downey, Limerick University, Ireland
Tony Skerritt, Limerick University, Ireland
Aisling Flanagan, Limerick University, Ireland
Lisa Connole, Limerick University, Ireland
Gerard Newsham, Limerick University, Ireland
Deirdre Fox, Dublin University College, Ireland
Brid Brosnan, Limerick University, Ireland