National Aeronautics and
Space Administration

NASA BPS Space Crops Program and Goal Update

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October 8, 2024

BPS
Biological & Physical Sciences

Agenda

- Science Highlights
  - Awards and Recognition
  - Completed ISS Experiments
  - Major grants
- Engagement and Outreach
- Publications
- Space Crops Roadmap Update

Space Crops-Science Highlights

Awards and Recognition

Recognition: Outstanding research accomplishments, mentorship, service

Dr. Anjali Iyer-Pascuzzi
Recognized by the American Society of Plant Biologists (ASPB) as one of 25 inspiring Women in Plant Biology.

Dr. Aubrie O'Rourke
2024 Early Career Achievement Medal. Significant performance within 10 years of service to NASA mission.

Drs. Sarah Wyatt and Raymond Wheeler
Elected as 2023 ASGSR Fellows for distinguished scientific and social contributions to the advancement of gravitational and space research through research, education, mentoring, outreach, and professional and public service.

BPS PI Conducts Own Suborbital Experiment on Blue Origin New Shepard-26

- Dr. Rob Ferl (University of Florida) is the first NASA-funded researcher to conduct his own experiment in space.
- The experiment launched from and returned to Blue Origin's West Texas Suborbital Launch Site on 08/29/24.
- One of the first experiments to examine genes that change expression as biology (plants) transition to and from microgravity.
- Pre and post launch activities were covered by more than 20 media outlets, including ABC, NBC, and CBS.

Dr. Rob Ferl exiting the NS-26 spacecraft after it returned to Earth.

Dr. Rob Ferl preparing to activate KFTs on NS-26.

Space Crops-Science Highlights

ISS Experiments Completed

Three ISS Plant and Microbial Experiments Completed

- **Plant Habitat-06 (PH-06) tomato plant immune response**
  - Launched on SpX-29 (11/09/23); returned on Ax-3 (02/07/24)
  - PI: Dr. Anjali Iyer-Pascuzzi, Purdue University

- **Advanced Plant Experiment-10 (APEX-10) tomato-microbe experiment**
  - Launched on NG-20 (01/30/24); returned on Crew-7 (03/11/24)
  - PI: Dr. Simon Gilroy, Univ. of Wisconsin-Madison

- **Biological Research in Canisters-25 (BRIC-25) *Staphylococcus aureus* bacterial experiment**
  - Launched on NG-20 (01/30/24); returned on SpX-30 (04/28/24)
  - PI: Dr. Kelly Rice, Univ. of Florida

Space Crops-Science Highlights

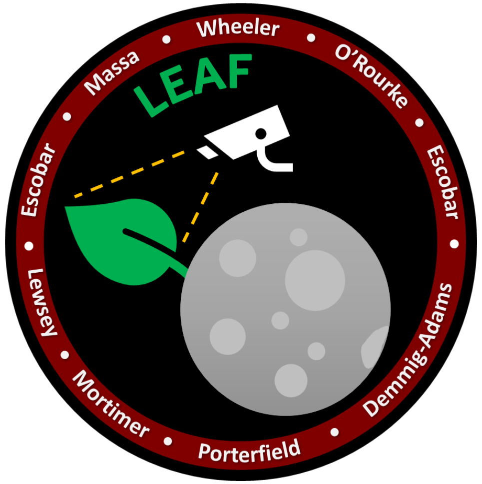
Major Grants Awarded

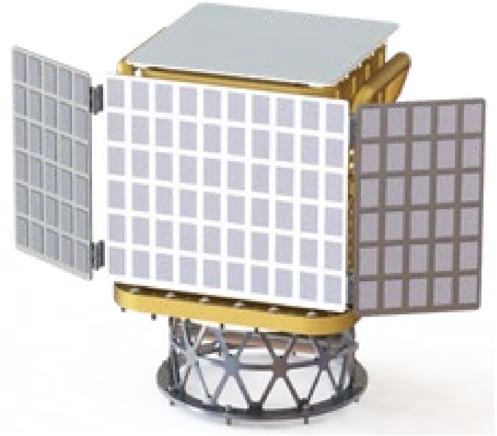
Lunar Effects on Agricultural Flora (LEAF)

PI: Christine Escobar [Space Lab Technologies, LLC]
Managed by PMPO, MSFC
Co-sponsored by NASA SMD Exploration Science Strategy Integration Office (ESSIO) and BPS

- Space Lab Technologies LLC-led research study with Deputy Principal Investigator and Co-Investigators from Kennedy Space Center, Purdue Univ., Univ. of Colorado-Boulder, and USDA [collaborator]
- Selected through the Artemis 3 Deployed Instruments solicitation as a candidate for lunar surface deployment
- Will enable the first detailed investigation on the effects of the lunar surface environment on plant physiological processes
- Aims to understand how plants grow in partial gravity and in lunar surface radiation environment; provide data for future crop growth methods and technologies sustaining lunar habitation and beyond

LEAF Specimens:Arabidopsis thaliana, Wolffia australiana (duckweed), and *Brassica rapa*





LEAF payload concept
(Credit Space Lab Technologies)

Space Crops

Engagement and Outreach

International Space Life Sciences Working Group (ISLSWG)

- ‘Plants in Space’ workshop held at 28^{th} European Low Gravity Research Association (ELGRA) biennial meeting in Liverpool, UK (Sept. 3-6, 2024)
- Organized by NASA and the German and Italian Space agencies (DLR, ASI)
- 200 delegates attended the ELGRA meeting; 50 international space agency delegates presented at the ISLSWG workshop
- Viewpoint article capturing the main points raised at the workshop will be submitted to the *New Phytologist* journal (March. 2025)

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Dr. Lynn Harrison, NASA Space Biology Program Scientist, participating in a cross-agency panel on the future of microgravity research

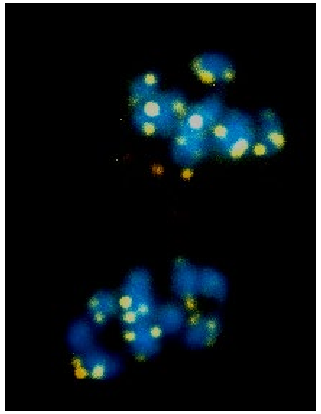
Space Crops

Representative publications
from a total of 37

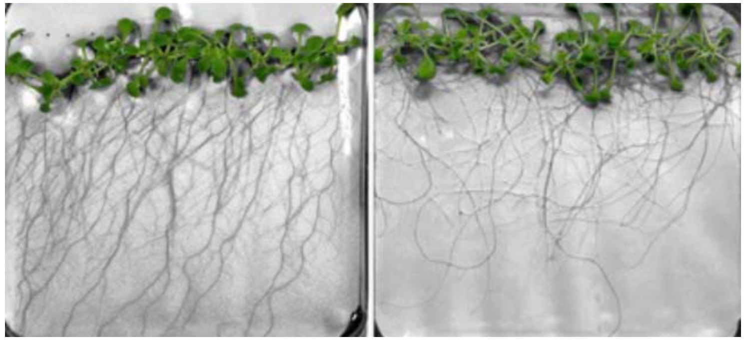
Spaceflight reveals insights into telomere function that may help plants survive harsh environments

Citation: Barcenilla BB, Meyers AD, Castillo-González C, Young P, Min JH, Song J, Phadke C, Land E, Canaday E, Perera IY, Bailey SM, Aquilano R, Wyatt SE, Shippen DE (2023) *Nature Communications*. 14(1):7854. doi: 10.1038/s41467-023-41510-4.

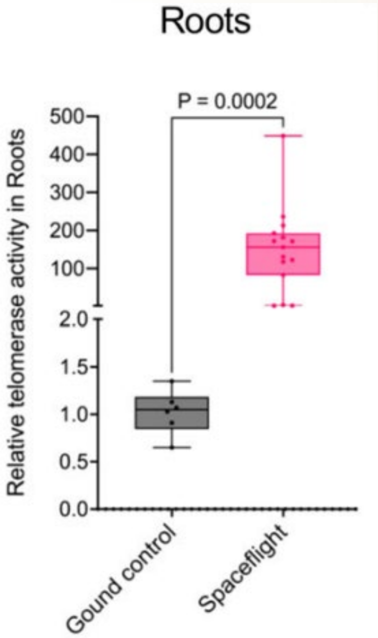
- Repetitive DNA sequences called telomeres are protective structures at the end of chromosomes that serve as biomarkers of the health of an organism.
- An enzyme called telomerase maintains the length of telomeres.
- Telomere length in roots of *Arabidopsis thaliana* plants grown on the ISS remained unchanged despite exhibiting enhanced telomerase activity.
- Results indicate a novel protective function of telomerase in plants that is independent of telomere length.



Telomeres (yellow) in Arabidopsis chromosomes (blue)



Ground control Spaceflight



Insights into how superelevated CO_2 affects plant growth has implications for crop cultivation in space

Citation: Wheeler, R.M., Spencer, L.E., Bhuiyan, R.H., Mickens, M.A., Bunchek, J.M., van Santen, E., Massa, G.D., & Romeyn, M.W. (2024). Effects of Elevated and Superelevated Carbon Dioxide on Salad Crops for Space. *J. Plant Interactions* 19 (1) https://doi.org/10.1080/17429145.2023.2292219

Citation: Kennebeck, E. J., & Meng, Q. (2024). Mustard 'Amara' Benefits from Superelevated CO2 While Adapting to Far-red Light Over Time. *HortScience*, 59(2), 139-145. https://doi.org/10.21273/HORTSCI17522-23

- Space habitats accumulate CO_2 because of human exhalation, which could affect the crops that will be used to supplement astronaut diets in space.
- Results show that crop species, cultivar, and light quality influence crop growth and nutritional qualities under ISS-like CO_2 levels.
- Results can help optimize environmental parameters and down selection of crops for future space habitats.

Space Crops

Roadmap Update

Thriving in Space

Revolutionary research in extraordinary places.

Precision Health	Space Crops	Quantum Leaps	Foundations	Space Labs
Leveraging space to unlock the secrets of aging and disease	*Boldly growing where no one has grown before*	*Unraveling mysteries of the universe*	*Revealing the novel behaviors of fluids, fire, and materials in space*	*Accelerating the pace and productivity of research*

Goal Overview: Space Crops

Reviewed plant science portfolio to identify gaps and opportunities

Revisit space crop gaps and map to KSQs

Prioritize objectives/ deliverables

Complete roadmap and accompanying narrative (i.e., Space Crops Science Plan)

Decadal and Moon to Mars (M2M) Alignment : Space Crops

Most Relevant Decadal Themes and Research Campaign

- Advances the Adapting to Space and Living and Traveling in Space Themes.
  - Transition to/from space
  - Genetic diversity & life history
  - Interactions between organisms
  - Multigenerational effects
  - Integration of biological & abiotic systems
  - Behavior of fluids in space
- Advances the Bioregenerative Life Support Systems (BLiSS) research campaign.

Most Relevant M2M Objectives

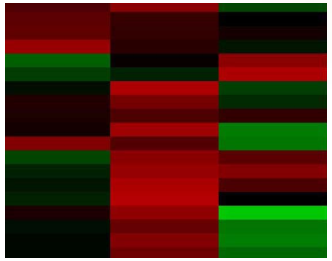
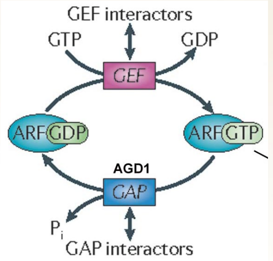
- HBS-1LM - Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
- AS-5LM: Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.

Examples of guiding questions for roadmapping

- What role will model plants play?



- How do we make a leap from primarily descriptive science to more mechanistic understanding of plant biological processes in space?

- What are top technological needs and science questions that need to be answered to successfully grow crops in space?


Relevance to Decadal Survey

GAPS

- Environmental Control
- Plant Environmental Response
- Crop Performance
- Horticultural Practice
- Produce Safety

SUB-GAPS (from >60)

- Water/Nutrient Delivery
- Gravity
- Radiation
- Atmosphere
- Yield
- Harvest Index
- Seed handling
- Harvesting
- Microbiome

RELEVANT KSQs

- KSQ1 – Space environment influence on biological mechanisms (e.g., xylem structure and hydraulics, nutrient uptake)
- KSQ7 – Phenomena that govern behavior of fluids in space environments

Progress with Space Crops Roadmapping

Objective:

Lunar Crops for Whole Food Nutrition and Mental Well-Being

- Define subobjectives/disciplines – Plant/Crop Physiology, Ecology, Microbiology, Molecular biology
- Prioritize space stressors – partial gravity, magnetic fields, radiation, growth substrates
- Define measurable outcomes – metrics that indicate progress toward an objective. How do we know if we are achieving the objective?

Architecting from the Right,

Executing from the Left

INVESTIGATIONS → THEMES* → GOALS

THEMES*	GOALS
TISSUE CHIPS ACCELERATED AGING & DISEASE MICROBIOLOGY SYSTEMS BIOLOGY	Precision Health
REGOLITH/SOIL BIOREGENERATIVE LIFE SUPPORT SYSTEMS CROP SPECIES CROP PRODUCTION SYSTEMS	Space Crops
COLD ATOMS/ATOM INTERFEROMETRY QUANTUM ENTANGLEMENT LUNAR LASER RANGING ATOMIC CLOCKS	Quantum Leaps
CRYO FLUIDS & THERMAL MANAGEMENT ~~IN SPACE~~ FIRE SAFETY RECYCLING & SUSTAINABILITY MANUFACTURING & PROCESSING IN SPACE	Foundations
LEO/COMMERCIALLY ENABLED RAPID SPACE SCIENCE GATEWAY LUNAR SURFACE MARS	Space Labs

**Draft – subject to change*

Space Crops Vision

Crop suitability
and engineering
testing and validation

Robust Earth analogs
and Low Earth Orbit
Lunar surface
infrastructure

Enable

Understand

Insights into
plant adaptation to
multiple space stressors
from the molecular
to ecosystem levels

Demonstrate

Implement

Early Lunar outpost
for plant research
and whole food
crew nutrition