Food Production for Space Exploration

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Space Food Production

- **Goal:** To produce *safe*, *nutritious*, *appealing* food to supplement a stored diet
  - As mission duration increases, a greater percentage of the diet might be produced

- **Key Factors:**
  - Production in controlled environments
    - Any solar light reduced and indirect
    - High CO₂ levels likely (ISS ≥3000 ppm)
    - Common environments for multiple crops
    - Crop scheduling is critical
  - Power, mass, volume, and crew time must be minimized
  - Sustainability - minimizing waste, nutrient recycling
  - Biotic stresses - carried from Earth, mutation
  - Abiotic stresses - related to micro or fractional gravity

- **Opportunities:**
  - Designer plants for space growth and nutrition
  - Automation
  - In Situ Resource Utilization (Regolith, CO₂, water)
Space Food Production Challenges

**Space**
- Microgravity
- Fluid movement
- No convection

**Surface**
- Water recycling
- Radiation
- Pressure
- Dust
- Micrometeorites

**Crop**
- Plant size
- High CO₂
- Food safety
- Nutrient output
- Sustainability
- Productivity
- Stress tolerance
- Environmental optimization
- Sustainability
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FARMING ON THE MOON

Farming on the moon will be mostly done ‘indoors,’ under a large plastic dome. Carbon Dioxide will be pumped in and sunlight will pour down on the plants. Special types of plants will be developed to give high energy foods to compensate for the pioneers’ lack of meat. Certain plants like strong cactus that can withstand the blistering rays of the sun, will be able to grow ‘outdoors’ on the moon.

See Card No. 62—MOON TRAINS

TARGET: MOON
FARMING ON THE MOON
Luna City

- agriculture part of life
- support
- transparent domes realistic?
- dangers of surface living
- problems with lunar agriculture
Plant Factories
South Pole Greenhouse

Photo from “On the Ice” Blog of Russ Durkee
The International Space Station
Designed and built by Orbital Technologies Corporation (ORBITEC)
Example crops tested in plant pillows

- Red lettuce
- Swiss chard
- Radish
- Dwarf Chinese cabbage
- Snow pea
Crop Selection for VEG-01

- Reliable germination
- Rapid growth
- Low native microbial levels
- Palatability / acceptability
- Attractiveness
- Antioxidants

Sent two sets of ‘Outredgeous’ lettuce and one set of ‘Profusion’ zinnia pillows
Veggie Installation

Veggie was installed in the ISS Columbus Module on 5/7 by Steve Swanson and Rick Mastracchio
Veg-01 initiation
Veg-01 wick opening (3 DAI)

Veg-01 on-orbit wick opening assisted seedling growth (3 days after initiation)
Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources
Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources

- Pillow B did not germinate
- 5 pillows contained seedlings
Veg-01 water stress

Veg-01 on-orbit plants exhibited low water response characteristics. Water was added directly to pillows to ensure water availability for the seedlings.
Veg-01 water stress

Plants in pillows A and C grew well
Plants in pillows D, E, and F exhibited stunting and water stress
D ultimately recovered and E and F died
Veg-01 Harvest (33 DAI)
Environment Inside Veggie during VEG-01

- **Humidity (%)**
- **Temperature (°C)**

- HOBO Data Logger moved to right side on 5/21/2014
- HOBO Data Logger moved to right-back on 5/21/2014
- Possible pillow overfill?
- Harvest

*Dates: 5/7/2014 - 6/11/2014*
VEG-01 Sample Analysis

• Fresh Mass
• Culturable microbial assessment:
  – Plants
  – Water
  – Pillow components
• Identification of cultured microbes
• RNA sequencing / ID of total microbial population
• Anthocyanin/Antioxidant/Phenolic Analysis
• Elemental analysis of plants and water
• X ray tomography of pillows
### Fresh Mass

<table>
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<tr>
<th></th>
<th>Flight</th>
<th>Ground</th>
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<tbody>
<tr>
<td>Number</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Average FM</td>
<td>20.61 g</td>
<td>15.29 g</td>
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<tr>
<td>SD FM</td>
<td>11.66 g</td>
<td>9.60 g</td>
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<tr>
<td>Max</td>
<td>31.51 g</td>
<td>26.11 g</td>
</tr>
<tr>
<td>Min</td>
<td>8.31 g</td>
<td>2.81 g</td>
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</table>

Sample priority:
1. Microbial analysis
2. Anthocyanin/Antioxidant/Phenolic Analysis
3. Elemental analysis of plants

Only samples of >19 g could be used for all three.
Microbial Assessment of Plants

- *E. coli, S. aureus, Salmonella* sp. not found on any plants.
- Aerobic plate counts less than limit for non-thermostabilized food on all flight plants and all but one ground plant (unexplained).
- Total yeasts and molds all below limit except on one flight plant (plant C, the largest, slightly over).
- Bacterial and fungal species isolated appear to be typical station microbes. There were some differences in the community from the ground set.
- Crew were approved to consume produce with precautionary wiping (this took > 6 months!).
Veg-01 Second Crop

- Modified watering procedures, increased photo frequency
- Initiated by Scott Kelly on July 8, 2015 from seeds previously sent
- Grown by Scott Kelly and Kjell Lindgren
- Water stress observed but astronauts intervened and grew 5 plants
- ½ the produce for consumption, ½ for science
- Plants harvested Aug. 10, 2015, live on NASA TV
- Science samples frozen and returned May, 2016.
Sanitizing Produce
Astronaut Comments

- **Scott Kelly**
  - the logistical complexity of having people live and work in space for long periods
  - the supply chain that is required
  - For Mars, need a space craft that is more self-sustainable with regards to its food supply

- **Kjell Lindgren**
  - benefit of eating the fresh food
  - contribution that plants have to the ISS ecosystem
  - psychological benefit - it’s really fun to see green growing things in the sterile environment of the ISS
Veg-01 Third Crop - Zinnia

- Directly watered plants after initiation, decreased photos to reduce crew time demands
- Initiated on Nov. 16, 2015 from seeds previously sent
- Grown by Kjell Lindgren and Scott Kelly
- Plants received too much water; fungus developed
- Mitigation attempted but several plants were lost before flowering
- Autonomous gardening started in Dec.
- Plants harvested Feb. 14, 2016
- Samples frozen and returned May, 2016
Zinnia data to inform on:
• Long term watering
• Microbial issues
• Flooding and air flow
• Mitigation strategies
• Flower development
• Seed formation and viability
• Human factors
• Chemistry and microbiology
• Plant pathogens on ISS
Water Issues / Consequences

Guttation and Leaf Curling

Fungal Development & Abnormal Growth
Veg-01 Zinnia Flight Flowers
Valentine’s Day Bouquet on the ISS
Next Steps

- Veg-03 ‘Tokyo bekana’ cabbage / ‘Outredgeous’ lettuce
  - Launched on CRS-8 (Feb. 8, 2016)
  - Cut-and-come-again testing

- Developing plans to pre-stage pillows and send seeds separately

- Crop testing of leafy greens, peppers, tomatoes - at KSC and in schools

- Testing light quality and fertilizer for Veg-04 ‘Tokyo Bekana’ and Veg-05 dwarf tomato
Thank you!

- Veggie and VEG-01 teams at KSC and ORBITEC
- Astronauts Steve Swanson, Rick Mastracchio, Scott Kelly, Kjell Lindgren
- Payload Operations and Integration Center
- NASA’s Space Life and Physical Sciences, ISS Program, Human Research Program

Veggie
Send more seeds!
We are hungry.
-Rick Mastracchio

Next to fly:
NASA’s Advanced Plant Habitat