Weaving Together Space Biology and the Human Research Program: Selecting Crops and Manipulating Plant Physiology to Produce High Quality Food for ISS Astronauts

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Human Research Program (HRP) 
Advanced Food Technology (AFT) Project Long 
Duration Food System Research Plan

- Continuing research to improve prepackaged system

- Supplement with pick and eat salad crops
Pick-and-eat salad-crop productivity, nutritional value, and acceptability to supplement the ISS food system

**Aim:** To examine light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, organoleptic acceptability, nutritional value, and behavioral health benefits.

**Team Components:**
- KSC: Food Crop Production, Microbiology
- JSC: AFT, BHP, Statistics
- Purdue: Food Crop Production
- ORBITEC: Food Crop Production, Lighting, Software
- Florikan: Fertilizer Consultants

Veggie is currently on ISS in the Columbus module.
The Foundation

• Long history of NASA-funded research on LED lighting for plants and bioregenerative life support systems at ORBITEC, Purdue University and KSC

• HRP AFT trade study comparing food production to a packaged diet

• SLPS-funded NASA Postdoctoral Program Research and Veggie Hardware Validation Testing

• Collaboration between KSC and JSC HRP on Veggie crew questions and food consumption approvals

• HRP-funded crop selection studies:
  • Leafy Greens
  • Dwarf Tomato and Pepper

• Florikan fertilizer expertise
Specific Objectives of the Project

• Specific aim 1: Evaluate the effects of four light treatments and three different fertilizer compositions on the yield, morphology, organoleptic acceptability, and nutritional attributes of leafy greens during flight-definition and flight testing.

• Specific aim 2: Perform cultivar selection and evaluate the effects of four different red: blue light treatments and three different fertilizer compositions on the yield, morphology, organoleptic acceptability, and nutritional attributes of dwarf tomato during ground and flight tests.

• Specific aim 3: Perform hazard analysis, develop plans for minimizing microbial hazards, and screen flight-grown produce for potential pathogens.
Proposed food system foci to test the factors of spaceflight, light quality, and fertilizer.
Leafy Greens - Candidates

• ‘Tyee’ spinach
• ‘Flamingo’ spinach
• ‘Outredgeous’ red romaine lettuce
• ‘Waldmann’s dark green leaf lettuce
• ‘Bull’s Blood’ beet
• ‘Rhubarb’ Swiss chard
• ‘Tokyo Bekana’ Chinese cabbage
• Mizuna
Growth Studies

Plants are grown in a controlled environment chamber at KSC, with environmental conditions set to mimic those on ISS (Temperature, RH, CO₂, Light).
Selection Criteria Overview

• Horticultural factors
  • Germination, ease of growth, amount of growth (food), size

• Dietary factors
  • Percent dry matter
  • Elemental Factors - Composition of key elements (K, Fe, Ca, Mg)
  • Nutrient Factors - Beneficial phytonutrients (Vitamin K, Lutein, Zeaxanthin, Antioxidants)

• Organoleptic factors
  • 9-pt Hedonic Scale: Overall taste, Appearance, Color, Bitterness, Flavor, Texture
  • 5-point Just About Right Scale: Crispness, Tenderness
Weighting and Ranking

• Weighting factors were developed for each parameter based on subjective importance.

• Data were normalized, weighted, and ranked.

• Divided into:
  • Horticultural Factors
  • Elemental Factors
  • Nutrient Factors
  • Organoleptic Factors

• 8 varieties were down selected to 4 for nutrient and organoleptic evaluation.

• 4 crops were grown and shipped to JSC for organoleptic testing.

• Final ranking performed on down selected crops.

• Similar process conducted for subsequent test crops
Overall Ranking

• Down selected to top four based on plant growth and elemental factors

• Further selection based on other nutrients and organoleptic factors leads to Overall Ranking
Leading to....

• Preparation of top candidate for flight testing in Veggie
  • Seed sanitation and positioning tests
  • Flight prep (Veg-03) of ‘Tokyo Bekana’ Chinese cabbage as well as previously flown ‘Outredgeous’ lettuce
  • Attempted to launch SpaceX-7, will re-fly SpaceX-8
  • Will buy down risk for red:blue LED light testing flight experiment
Dwarf Tomato - Candidates

- ‘Red Robin’ tomato
- ‘Sweet ‘n’ neat’ tomato
- ‘Mohamed’ tomato
- ‘Patio Princess’ tomato
- ‘Tiny Tim’ tomato
- ‘Tumbler’ tomato
Dwarf Pepper - Candidates

- ‘Chablis’ pepper
- ‘Pompeii’ pepper
- ‘Fruit Basket’ pepper
- ‘Red Skin’ pepper
- ‘Cajun Belle’ pepper
- ‘Sweet Pickle’ pepper
Selection Criteria

• Horticultural factors
  • Canopy area, height, # fruit/plant, total fruit mass, days to first fruit, percent moisture, ¹trueness to type, ²mass per fruit

• Nutritional factors
  • Composition of key elements (K, Fe, Ca, Mg)
  • Beneficial phytonutrients (Phenolics, Antioxidants, Anthocyanins (¹ripe and unripe fruit), Vitamin K, Lutein, Zeaxanthin, ¹Lycopene)

• Organoleptic factors
  • 9-pt Hedonic Scale: Overall taste, Appearance, Color, Aroma, Flavor, ²Texture
  • 5-point Just About Right Scale: Sweetness, Juiciness, ¹Tartness, ²Astringency

(¹ tomato, ²pepper)
Overall Ranking

• Down selected to top three based on plant growth factors

• Further selection based on other nutrients and organoleptic factors leads to Overall Ranking
Next Steps – Plant Testing

• Red and Blue LED light & Fertilizer testing with top leafy green and tomato
  • Testing at KSC, Purdue, ORBITEC
  • Four light regimes will be assessed:
    • 90% R: 10% B, 70% R: 30% B, 50% R: 50% B, split treatment of ¾
      90%:10% + ¼ 50%:50%

• Three fertilizer release treatments will be assessed:
  • 100% 180-day release, 66% 180 d: 34% 100 d, 50% 180 d: 50% 100 d
  • 16-6-8 formulation for leafy crop, 14-4-14 for tomato

• Plants assessed for growth, nutrition, and sent to JSC for taste tests

• Ground testing will identify top fertilizer treatment and top 2 light treatments

• Work to manifest and fly second Veggie and then test each crop under top 2 light treatments on ISS
**Space Food Safety Component**

- Hazard Analysis and Critical Control Point (HACCP) Plan
  - Assess risks
  - Evaluates operating parameters
  - Sets controls to mitigate risk

- Task will involve
  - Assessment of crop microbiology
  - Working to develop standards for space-grown produce
  - Working with stakeholders to implement regular crew consumption
Behavioral Health Component

• A highest priority stressor anticipated for a long duration mission is lack of sensory stimulation due to isolation and confinement

• Plants have potential countermeasure benefits:
  • Dramatic visual relief
  • Growth and development provide cues to time passing
  • Tending plants can be relaxing
  • Fresh vegetables for flavor and texture dietary variety
  • Scents, colors and textures augment environment

• Flight approach: Questionnaires with Visual Analog Scales to minimize time required. Also open-ended options.

  Tending to the plants is enjoyable
  |__________________________________________|
  |Strongly Disagree                        |Strongly Agree|
Thank you!

• Other Grant team members:
  • Cary A. Mitchell (Purdue)
  • Robert C. Morrow (ORBITEC)
  • Alexandra M. Whitmire (Wyle/JSC)
  • Robert Ploutz-Snyder (USRA/JSC)
  • Florikan

• Crop Selection (KSC):
  • Gary Stutte
  • LaShelle Spencer
  • Jeff Richards

• Veggie team
• De Ante Cooper, Bridgit Higginbotham, Brian Gore
• HRP and SLPS for co-funding the 2015 ILSRA award – MTL# 1075.
Questions?
Backups
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weighting</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant Growth Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germination</td>
<td>x 1.5</td>
<td>Germination indicates how easy plants are to grow.</td>
</tr>
<tr>
<td>SPAD</td>
<td>x 0</td>
<td>SPAD is a factor of plant growth (chlorophyll content) but not important for diet or a yield parameter</td>
</tr>
<tr>
<td>Volume</td>
<td>x 1.5 (inverted)</td>
<td>Volume is important because it gives information on how much space the crop will occupy and it is a constraint for spaceflight</td>
</tr>
<tr>
<td>FM</td>
<td>x 2</td>
<td>Fresh mass indicates crop yield - a principal factor</td>
</tr>
<tr>
<td>Days to maturity</td>
<td>x 1.5 (inverted)</td>
<td>Indicates how quickly plants could be grown</td>
</tr>
<tr>
<td>% moist</td>
<td>x 1 (inverted)</td>
<td>Percent moisture indicates amount of dry mass ~calories</td>
</tr>
<tr>
<td><strong>Elemental Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>x 1</td>
<td>Calcium is important but desired amount remains unclear</td>
</tr>
<tr>
<td>Fe</td>
<td>x 1.5 (inverted)</td>
<td>Too much iron can cause issues so low iron is desired</td>
</tr>
<tr>
<td>K</td>
<td>x 2</td>
<td>Space diet is deficient in Potassium - a principal factor</td>
</tr>
<tr>
<td>Mg</td>
<td>x 1.5</td>
<td>More Magnesium is desirable</td>
</tr>
<tr>
<td>Parameter</td>
<td>Weighting</td>
<td>Rationale</td>
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<td>---------------</td>
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<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Nutrient Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORAC</td>
<td>x 1.5</td>
<td>Antioxidants may help protect from radiation damage</td>
</tr>
<tr>
<td>Lutein</td>
<td>x 1.5</td>
<td>Lutein is potentially important for eye health</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>x 1.5</td>
<td>Zeaxanthin is potentially important for eye health</td>
</tr>
<tr>
<td>Vitamin K</td>
<td>x 1.5</td>
<td>The space diet is deficient in Vitamin K</td>
</tr>
<tr>
<td><strong>Organoleptic Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall taste</td>
<td>x 2</td>
<td>Overall taste is a principal factor, all other factors feed into this factor</td>
</tr>
<tr>
<td>Appearance</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of appearance in overall acceptability impact.</td>
</tr>
<tr>
<td>Color</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of color in overall acceptability impact.</td>
</tr>
<tr>
<td>Bitter</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of bitterness in overall acceptability impact.</td>
</tr>
<tr>
<td>Flavor</td>
<td>x 1.5</td>
<td>Overall flavor indicates acceptability of factors of taste and aroma combined</td>
</tr>
<tr>
<td>Texture</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of texture in overall acceptability impact.</td>
</tr>
<tr>
<td>Crispness</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of crispness in overall acceptability impact.</td>
</tr>
<tr>
<td>Tenderness</td>
<td>x 1</td>
<td>Normal weighting, indicates influence of tenderness in overall acceptability impact.</td>
</tr>
</tbody>
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