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

Gioia Massa[1], Mary Hummerick[2], Grace Douglas[3], Raymond Wheeler[1]

[1] NASA-Kennedy Space Center, [2] Engineering Services Contract-Vencore, KSC, [3] NASA-Johnson Space Center

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:

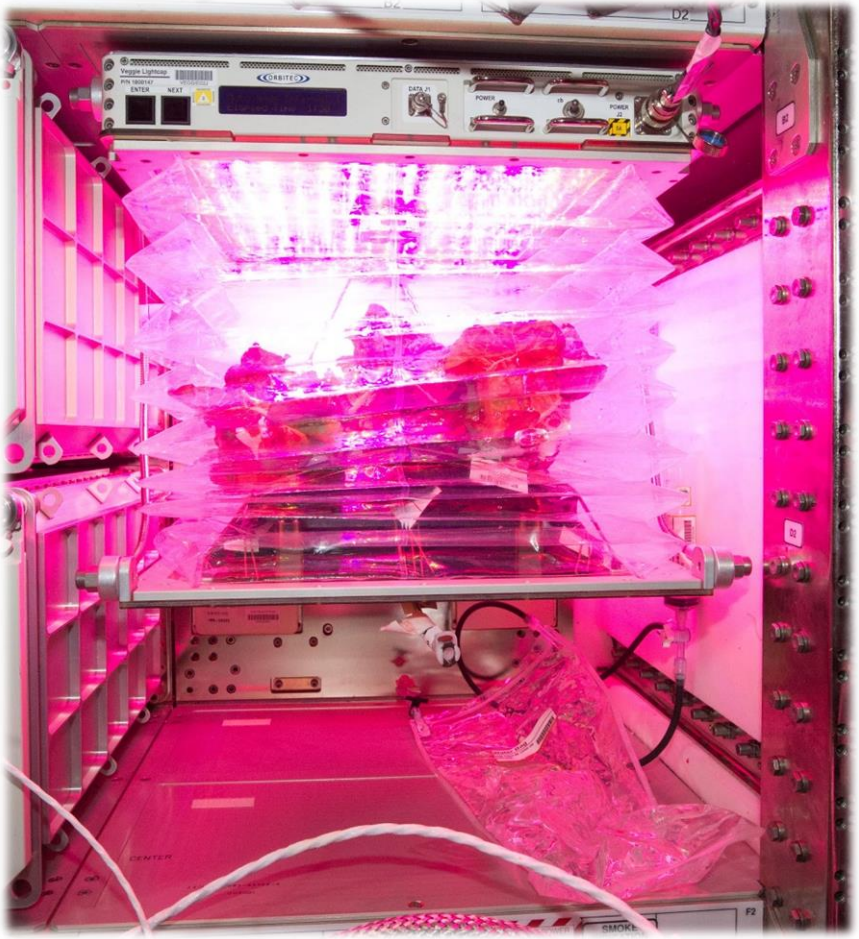
KSC: Food Crop Production, Microbiology

JSC: AFT, BHP, Statistics

Purdue: Food Crop Production

ORBITEC: Food Crop Production, Lighting, Software

Florikan: Fertilizer Consultants



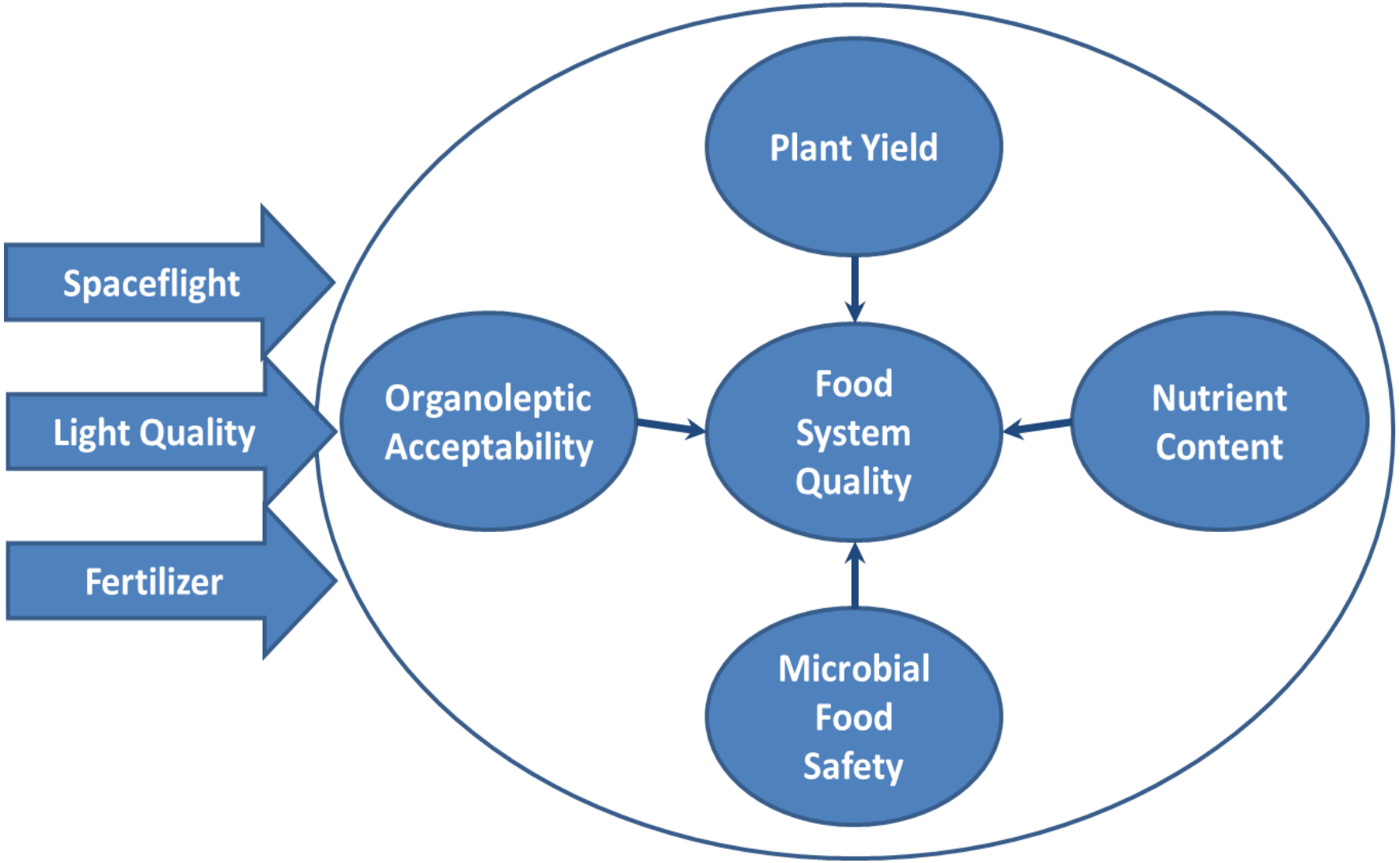
Veggie is currently on ISS in the Columbus module.

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

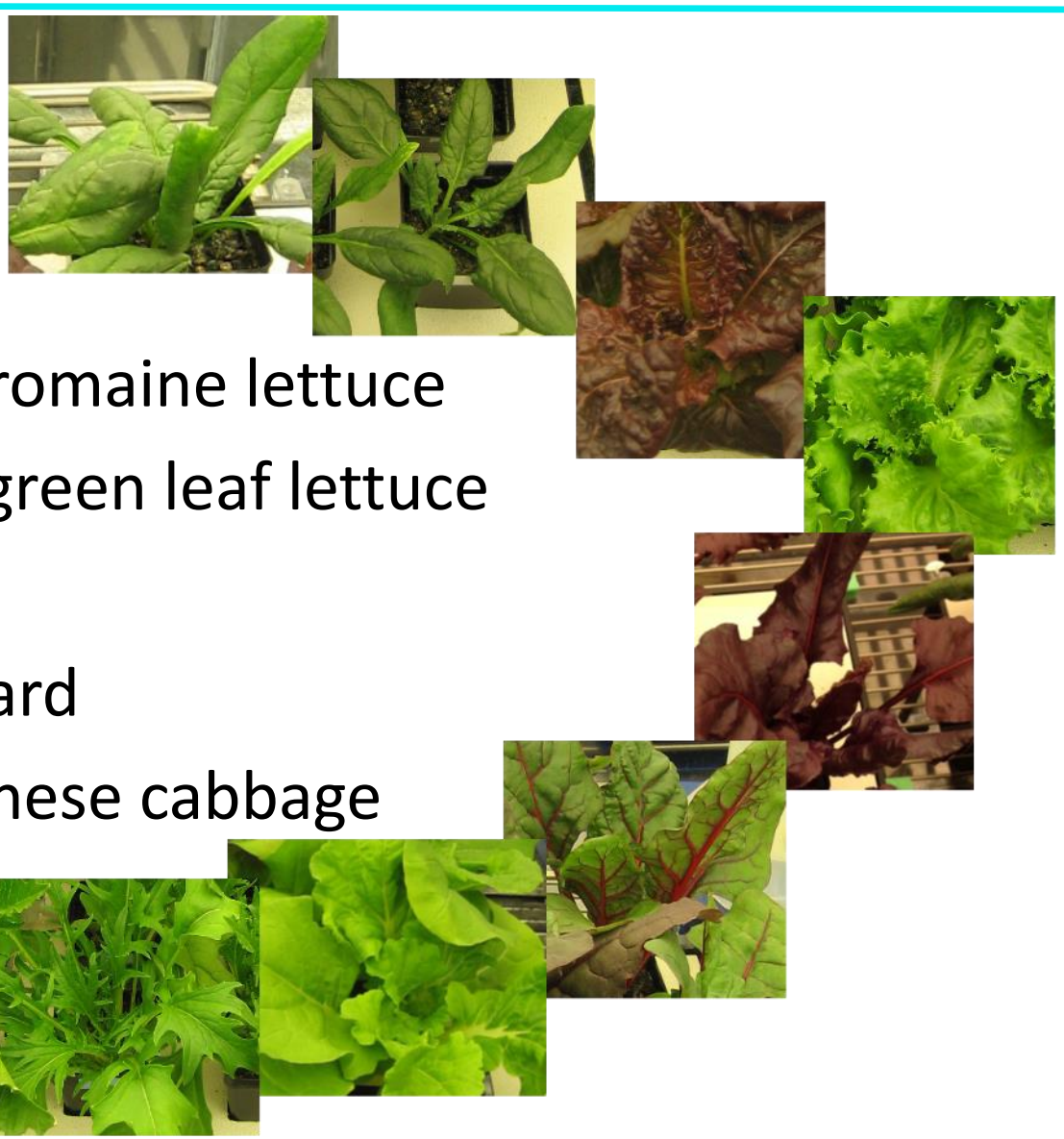
- **Specific aim 1:** ***Evaluate the effects of four light treatments and three different fertilizer compositions on the yield, morphology, organoleptic acceptability, and nutritional attributes of leafy greens during flight-definition and flight testing.***
- **Specific aim 2:** ***Perform cultivar 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.

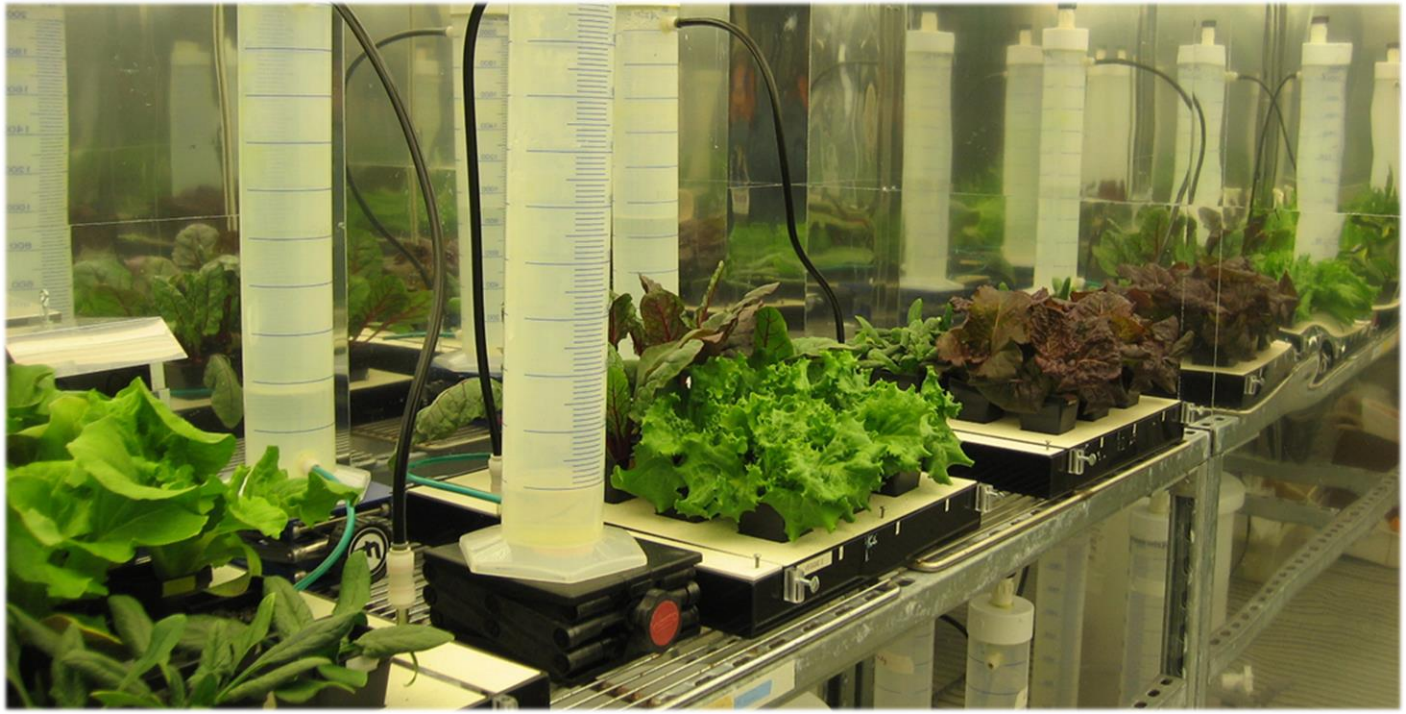
Leafy Greens - Candidates

- ‘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, CO_2, 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 **<u>Overall Ranking</u>**

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

‘Tokyo bekana’ Chinese cabbage seed orientation

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

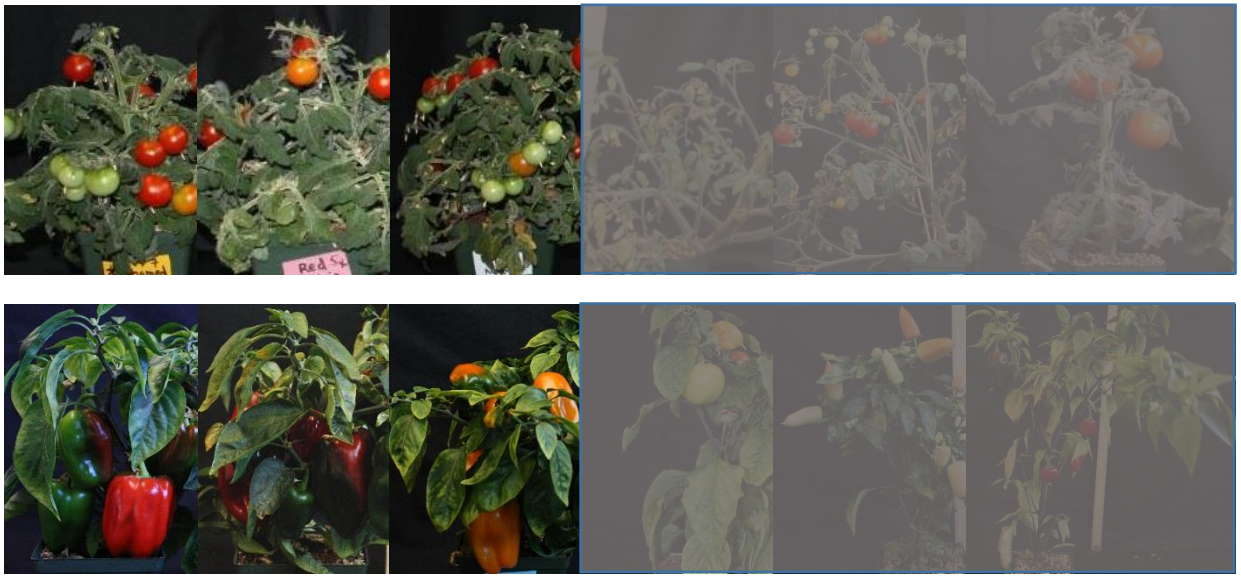
Selection Criteria

- Horticultural factors
  - Canopy area, height, # fruit/plant, total fruit mass, days to first fruit, percent moisture, [1]trueness to type, [2]mass per fruit
- Nutritional factors
  - Composition of key elements (K, Fe, Ca, Mg)
  - Beneficial phytonutrients (Phenolics, Antioxidants, Anthocyanins ([1]ripe and unripe fruit), Vitamin K, Lutein, Zeaxanthin, [1]Lycopene)
- Organoleptic factors
  - 9-pt Hedonic Scale: Overall taste, Appearance, Color, Aroma, Flavor, [2]Texture
  - 5-point Just About Right Scale: Sweetness, Juiciness, [1]Tartness, [2]Astringency

([1] tomato, [2]pepper)

Overall Ranking

- Down selected to top three based on plant growth factors



- Further selection based on other nutrients and organoleptic factors leads to **<u>Overall Ranking</u>**

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

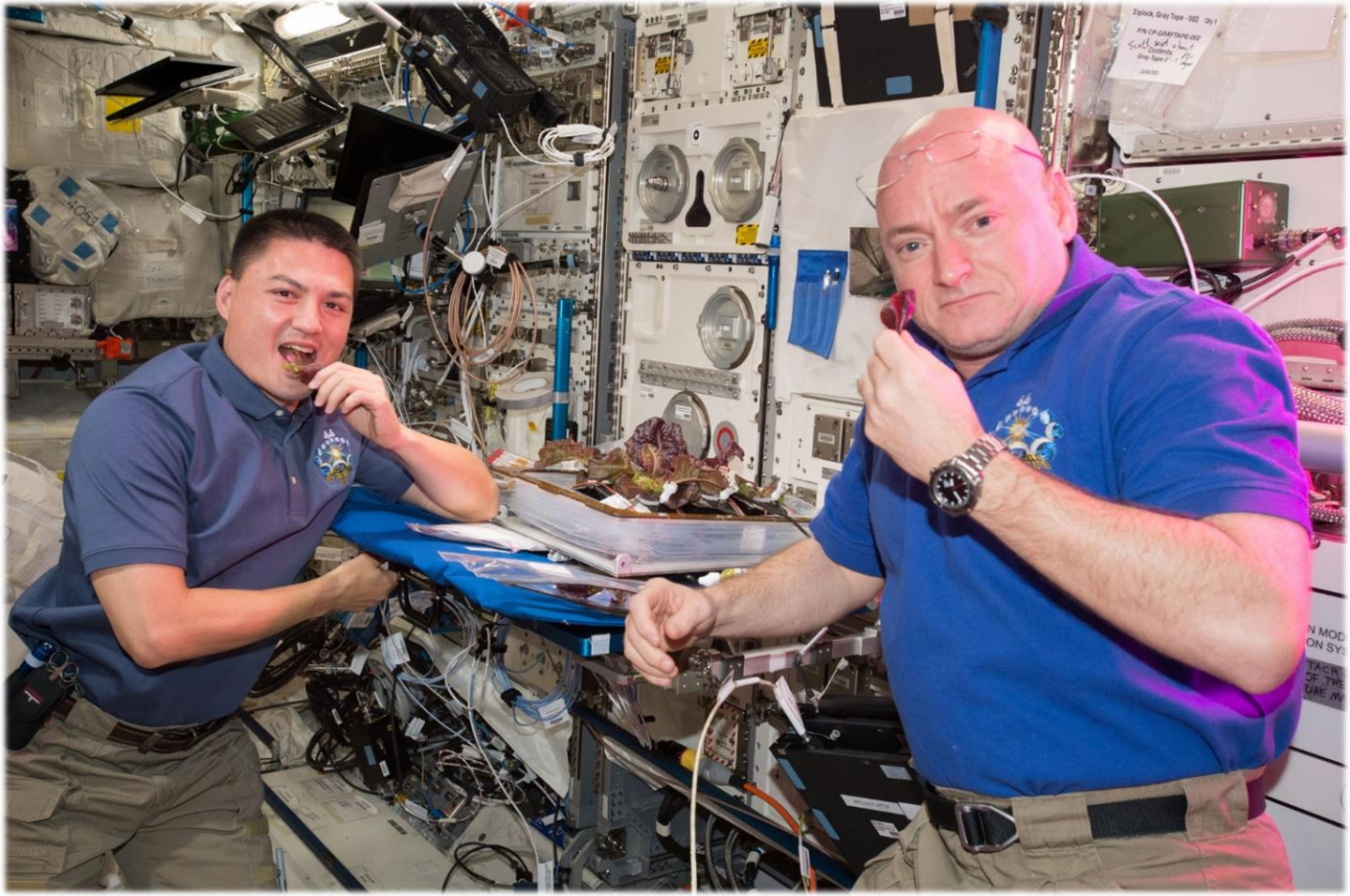
|_____|

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

Parameter	Weighting	Rationale
Plant Growth Factors		
Germination	x 1.5	Germination indicates how easy plants are to grow.
SPAD	x 0	SPAD is a factor of plant growth (chlorophyll content) but not important for diet or a yield parameter
Volume	x 1.5 (inverted)	Volume is important because it gives information on how much space the crop will occupy and it is a constraint for spaceflight
FM	x 2	Fresh mass indicates crop yield - a principal factor
Days to maturity	x 1.5 (inverted)	Indicates how quickly plants could be grown
% moist	x 1 (inverted)	Percent moisture indicates amount of dry mass ~calories
Elemental Factors		
Ca	x 1	Calcium is important but desired amount remains unclear
Fe	x 1.5 (inverted)	Too much iron can cause issues so low iron is desired
K	x 2	Space diet is deficient in Potassium - a principal factor
Mg	x 1.5	More Magnesium is desirable

Parameter	Weighting	Rationale
Nutrient Factors		
ORAC	x 1.5	Antioxidants may help protect from radiation damage
Lutein	x 1.5	Lutein is potentially important for eye health
Zeaxanthin	x 1.5	Zeaxanthin is potentially important for eye health
Vitamin K	x 1.5	The space diet is deficient in Vitamin K
Organoleptic Factors		
Overall taste	x 2	Overall taste is a principal factor, all other factors feed into this factor
Appearance	x 1	Normal weighting, indicates influence of appearance in overall acceptability impact.
Color	x 1	Normal weighting, indicates influence of color in overall acceptability impact.
Bitter	x 1	Normal weighting, indicates influence of bitterness in overall acceptability impact.
Flavor	x 1.5	Overall flavor indicates acceptability of factors of taste and aroma combined
Texture	x 1	Normal weighting, indicates influence of texture in overall acceptability impact.
Crispness	x 1	Normal weighting, indicates influence of crispness in overall acceptability impact.
Tenderness	x 1	Normal weighting, indicates influence of tenderness in overall acceptability impact.