

Fiscal Year:	FY 2018	Task Last Updated: FY 08/16/2018	
PI Name:	Massa, Gioia Ph.D.		
Project Title:	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System		
Division Name:	Human Research, Space Biology		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:			
Joint Agency Name:		TechPort:	No
Human Research Program Elements:	(1) HHC: Human Health Countermeasures		
Human Research Program Risks:	(1) Food and Nutrition: Risk of Performance Decrement and Crew Illness Due to Inadequate Food and Nutrition		
Space Biology Element:	(1) Plant Biology		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	(1) Bioregenerative Life Support		
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PI Organization Type:	NASA CENTER	Phone:	321-861-2938
Organization Name:	NASA Kennedy Space Center		
PI Address 1:	ISS Ground Processing and Research		
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City:	Kennedy Space Center	State:	FL
Zip Code:	32899-0001	Congressional District:	8
Comments:			
Project Type:	Flight	Solicitation / Funding Source:	2013-14 HERO NNJ13ZSA002N-ILSRA. International Life Sciences Research Announcement
Start Date:	09/01/2015	End Date:	08/31/2020
No. of Post Docs:	0	No. of PhD Degrees:	1
No. of PhD Candidates:	0	No. of Master' Degrees:	1
No. of Master's Candidates:	3	No. of Bachelor's Degrees:	
No. of Bachelor's Candidates:	15	Monitoring Center:	NASA JSC
Contact Monitor:	Douglas, Grace	Contact Phone:	
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Flight Program:	ISS		
Flight Assignment:	NOTE: End date changed to 8/31/2020 per PI (Ed., 8/17/18) NOTE: Element change to Human Health Countermeasures; previously Space Human Factors & Habitability (Ed., 1/18/17) NOTE: Period of performance changed to 9/01/2015-8/31/2018 (previously 7/1/15-6/30/18) per G. Douglas/HRP (Ed., 4/3/16)		
Key Personnel Changes/Previous PI:	August 2017: LaShelle Spencer and Matt Romeyn have been added as Co-Investigators as of August 23, 2017.		
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Grant/Contract No.:	Internal Project
Performance Goal No.:	
Performance Goal Text:	
Task Description:	<p>The capability to grow nutritious, palatable food for crew consumption during spaceflight has the potential to provide health promoting, bioavailable nutrients, enhance the dietary experience, and reduce launch mass as we move toward longer-duration missions. However, studies of edible produce during spaceflight have been limited, leaving a significant knowledge gap in the methods required to grow safe, acceptable, nutritious crops for consumption in microgravity. The “Veggie” vegetable-production system on the International Space Station (ISS) offers an opportunity to develop a “pick-and-eat” fresh vegetable component to the ISS food system as a first step to bioregenerative supplemental food production. We propose growing salad plants in the Veggie unit during spaceflight, focusing on the impact of light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, organoleptic acceptability, nutritional value, and behavioral health benefits of the fresh produce. Phase A of the project would involve flight tests using leafy greens. Phase B would focus on dwarf tomato. Our work will help define light colors, levels, and horticultural best practices to achieve high yields of safe, nutritious leafy greens and tomatoes to supplement a space diet of prepackaged food. Our final deliverable will be the development of growth protocols for these crops in a spaceflight vegetable production system.</p> <p>Specific aim 1: Evaluate the effects of four light treatments and two different fertilizer compositions on the yield, morphology, organoleptic acceptability, and nutritional attributes of leafy greens during flight-definition and flight testing.</p> <p>Specific aim 2: Perform cultivar selection and evaluate the effects of four different red: blue light treatments and two different fertilizer compositions on the yield, morphology, organoleptic acceptability, and nutritional attributes of dwarf tomato during ground and flight tests.</p> <p>Specific aim 3: Perform hazard analysis, develop plans for minimizing microbial hazards, and screen flight-grown produce for potential pathogens.</p>
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	<p>Research Project: Our work on “Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System” focuses on the development of a fresh food production capability on the International Space Station. Using the Veggie hardware we will develop light and fertilizer combinations that will help to generate nutritious and appealing leafy green vegetables and dwarf tomatoes that astronauts can consume in a safe manner. The results of this research will be directly translatable to Earth-based controlled environment production of these and similar crops in vertical farms and urban plant factories.</p> <p>The capability to grow nutritious, palatable food for crew consumption during spaceflight has the potential to provide health-promoting, bioavailable nutrients, enhance the dietary experience, and reduce launch mass as we move toward longer-duration exploration missions. However, studies of edible produce during spaceflight have been limited, leaving a significant knowledge gap in the methods required to grow safe, acceptable, nutritious crops for consumption in microgravity. The Veggie vegetable-production system on the ISS offers an opportunity to develop a “pick-and-eat” fresh vegetable component to the ISS food system as a first step to bioregenerative supplemental food production. Our goal is to grow salad plants in the Veggie unit during spaceflight, and assess the impact of light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, organoleptic acceptability, nutritional value and behavioral health benefits. Our work will help define light color ratios, fertilizer composition, and horticultural best practices to achieve high yields of safe, nutritious leafy greens and tomatoes to supplement a space diet of prepackaged food. Our final deliverable will be the development of growth protocols for these crops in a spaceflight vegetable-production system. This will help reduce the risk and close the gap of inadequate nutrition by helping us advance the development of bioregenerative food production to supplement the packaged diet for future space exploration.</p>
	<p>Crop Testing</p> <p>Mizuna: A number of tests were conducted with mizuna in both analog PONDS and in flight-like PONDS (water and plant containment) systems in preparation for the preflight science verification test. Each flight PONDS unit would hold one plant in a cylinder of granular rooting medium of arcillite, with the cylinder then supported in a plastic container that holds water. Two experiments were conducted in analog PONDS hardware focusing on the four different red (R): blue (B) light ratios of interest, and data on crop parameters including assessments of plant growth (fresh mass, area, volume, relative chlorophyll, leaf number, leaf area, dry mass) and chemistry/nutrient assessments (Ca, Fe, K, Mg, Lutein, Zeaxanthin) were conducted. 90% R :10% B light treatments and 50% R : 50% B treatments showed better fresh mass and lutein than in other treatments and because of these responses and similar levels of other nutrients to other treatments, these were the two light levels selected for follow on testing and flight experimentation. Additional ground tests were conducted comparing analog PONDS and flight-like PONDS systems in preparation for the preflight science verification test. At Kennedy Space Center (KSC), different methods of the cut-and-come-again, i.e., repetitive harvest techniques were tested in both types of hardware, with the “standard” removal of the outer oldest leaves compared to “major” removal, which removed large and medium leaves. Interestingly the type of PONDS analog had an impact on the most successful harvest strategy. Also there was a large impact on growth, with plants grown in the flight-like analog achieving a much greater mass than those in the original analog, likely due to a greater volume and oxygen exchange capacity. Although both techniques were similarly effective it was decided to proceed with the major cut-and-come-again approach for flight testing due to the ease of this technique and an ability to reduce chances of broken leaves in the Veggie hardware.</p> <p>At Purdue University, mizuna plants were grown in a growth chamber mimicking the same environmental and cultural conditions as for the Veggie plant-growth system on ISS in original Plants grew for 56 days under one of three light treatments: 90% Red : 10% Blue; 70% Red : 30% Blue; or 50% Red : 50% Blue. Large and medium-sized leaves from the three light treatments were harvested two times during the experiment: The first harvest occurred 28 days from planting, and the second harvest at 38 days from planting. In addition, whole plants were harvested at 56 days to end</p>

the experiment. Data from all harvests are consistent with the fact that red light enhances leaf expansion and blue light increases leaf number. Overall, a decrease in yield was noted over time and it is postulated that this decrease relates to mineral deficiency. Current studies are testing optimum fertilizer ratios for growing mizuna plants with cut-and-come-again harvesting practices. Similar work is also being conducted at KSC in the plant pillows. Although the PONDS hardware and analogs worked effectively on Earth, preliminary flight tests of this hardware indicated that it was not as effective in microgravity. Thus the VEG-04 experiment with mizuna has been transitioned to become a plant pillow experiment in Veggie and ground testing is required to optimize fertilizer formulation and growth duration for this different growing system.

Mizuna plants were grown at KSC in Veggie analog conditions and PONDS analog hardware under the two red: blue light treatments selected for flight evaluation and shipped overnight to the Johnson Space Center Space Food Systems Laboratory for evaluation. Produce was evaluated on a 9-point hedonic scale (1=dislike extremely – 9=like extremely) for Overall Acceptability, Appearance, Color, Aroma, Flavor, and Texture, and a 5 point Just-about-right scale (3= just about right, <3=too little, >3=too much) for Crispness, Tenderness, and Bitterness. The mizuna samples were not statistically significantly different in overall acceptability and fell within the range of most ISS products, which generally score from ~6.5-7.5.

Dwarf tomato: In preparation for flight tomato seed orientation was determined to be able to have the root emerge in the substrate. Tomato seed surface sterilization techniques were also established so ensure that plants would start germination without a microbial load on their seed surfaces. Preliminary fertilizer testing of 'Red Robin' tomato plants growing in original PONDS analog hardware was completed at KSC in the summer of 2017, and results indicated that plants grown using the T90 nano 14-4-14 fertilizer produced a slightly greater fresh mass of ripe fruit than plants grown with T100 14-4-14 nutricote fertilizer of standard prill size. Further testing was conducted in the fall of 2017 with tomato plants grown in these analog PONDS units using T90 fertilizer with the 4 light treatments discussed above for mizuna: 90 R : 10 B, 70 R : 30 B, 50 R : 50 B, and split. On average the 50 R : 50 B and 90 R : 10 B treatments produced the greatest amount of fruit and contained some of the best nutritional properties of tested light treatments. Similar tomato light and fertilizer experiments were conducted at ORBITEC/SNC; however, these tests were conducted with a coarser arcillite substrate and a slightly different PONDS analog configuration. Plants seemed less healthy, and in many cases plants grown with the T90 fertilizer did not survive. The analog PONDS growth system appears to have great sensitivity to arcillite particle size and fertilizer prill size. Smaller fertilizer prills like the T90 nano may sift down in this system and not provide sufficient nutrients in the growing zone in a coarser rooting substrate.

HACCP plan development: A hazard analysis critical control point (HACCP) plan is being developed based on baseline microbiological data and a risk assessment for crops grown in the VEGGIE in order to provide fresh food for the crew. The goal of this work is to develop a plan based on an evaluation of potential microbial risks associated with crops grown in Veggie, harvest methods, and pre and post-harvest procedures for reducing and/or preventing microbial contamination, the primary goal of a HACCP plan being prevention. Understanding the normal microbial populations on the variety of produce grown in Veggie and contamination prevention is necessary to provide safe palatable fresh food especially since specific and real time microbial monitoring methods are currently lacking for this purpose on ISS.

The hazard analysis includes verification of the procedures, and baseline microbiological data collected from ground and flight studies to ascertain normal microbial populations on the crops and Veggie components. As part of this work both 'Tokyo Bekana' Chinese cabbage and mizuna have been assessed for baseline microbial populations and specific pathogens when grown under the different test configurations. After the first harvest, microbial numbers generally increased in mizuna plants over repetitive harvest times but these numbers were similar between the major and standard cut-and-come-again harvest methods. Produce sanitizing wipes were very effective at removing both aerobic bacterial and fungal contaminants from leaves. 'Red Robin' tomato baseline assessment is underway.

Preflight testing and flight preparation: A series of preflight tests must be conducted before candidate payloads proceed to flight. Initially an Experiment Requirements Document (ERD) must be developed. This involves defining success criteria for flight. Following approval of the ERD, a preliminary Science Verification Test (SVT) is conducted in the flight hardware under ISS environmental conditions. The goal of the SVT is to test an investigation under flight-like conditions and to answer key questions within the investigation. For the VEG-04 and VEG-05 key open questions were on the watering frequency for the crops. Therefore in both the VEG-04 and VEG-05 SVT plant water use was tracked on a daily basis. Following SVT, if success criteria were met, an investigation can gain approval to move on to the Experiment Verification Test (EVT). All conditions, as nearly as possible, should replicate those that are planned for use in flight. If an EVT is successful, a payload is approved for flight. If either an SVT or an EVT fails to meet sufficient success criteria, a delta verification test will be conducted. In the period of performance for this grant an SVT and EVT were conducted for VEG-04, and an SVT was conducted for VEG-05.

The VEG-04 and VEG-05 SVT tests were conducted using the PONDS growth hardware. These tests were run at ISS conditions, and plant water use was monitored. For VEG-04 SVT, plants were harvested four times over a 55 day growth period. Regrowth was not exceptional, and thus a decision was made to modify the fertilizer formulation for the EVT. While the modification appeared successful, EVT had additional challenges, including faster growth than was observed for SVT, leading to increased water use and wilting of plants. At the same time the PONDS tech demo on the ISS did not work as expected in microgravity. These circumstances led to a change in plans and VEG-04 will now use plant pillows instead of the PONDS hardware. A delta EVT is being planned for VEG-04 in late August 2018. The VEG-05 SVT of tomatoes in PONDS was successful, and currently it is planned that tomatoes will continue to be grown in PONDS with modification of PONDS components and operations. Modifications of this system are being developed under an independent contract and a tech demo will be tested in ISS as early as December of 2018, with an EVT possible for VEG-05 in January 2019.

Questionnaires to survey astronaut mood in response to plant growth, as well as organoleptic analysis ratings for on-orbit produce consumption have been approved through the Johnson Space Center (JSC) eIRB process. Questions will be asked of all enrolled US Orbital Segment (USOS) crew members that will fly during the time that plants will be grown on ISS. Data will be collected pre-flight, in flight, and post flight. Organoleptic evaluations will be conducted by crew who are enrolled and available to taste produce during harvest events. Evaluation criteria for both VEG-04 and VEG-05 have been developed and entry of these evaluations has been made into a data collection platform. Informed consent briefings and crew participant enrollment in the studies are ongoing. Four participants have consented to date.

In addition to preparing science for the flight, the grant team has worked closely with payload developers to develop the contents for science and support kits which are being used for the preflight testing. Kits are being developed for the

Task Progress:

	<p>flight payloads and will be launched as accompanying hardware. A quantum meter was selected, manifested, and launched to the ISS in June of 2018. This meter will be used to measure the incident stray light coming into the Veggie hardware from overhead ISS lighting when Veggie lights are off, and allow us to set up similar ambient lighting conditions for ground control experiments. A divider has been built to separate the Veggie units to keep the light environments separate on the ground, and on the ISS, if needed (depending on their locations). Additionally it will provide a white surface which will allow good reflection of escaping light back into the chamber, thus helping to increase light uniformity within the Veggie chamber. ORBITEC/SNC has tested a number of materials to act as a reflective bellows, providing an essentially one-way mirror effect, reflective when the Veggie interior lighting is off, but translucent when the Veggie lighting is on. A good candidate material has been identified and may be used in future Veggie hardware upgrades if the science drives a need to reduce stray light into Veggie.</p> <p>Preflight preparation continues at all locations with the first flight operations scheduled to start in fall 2018 and subsequent flight tests in 2019.</p>
Bibliography Type:	Description: (Last Updated: 07/26/2024)
Abstracts for Journals and Proceedings	<p>Morsi AH. "Optimizing Spectra for Mizuna Grown On International Space Station." 2018 American Society for Horticultural Science meeting, Washington, DC, July 30-August 3, 2018.</p> <p>2018 American Society for Horticultural Science meeting, Washington, DC, July 30-August 3, 2018. , Aug-2018</p>
Abstracts for Journals and Proceedings	<p>Massa GD, Romeyn MW, Fritsche RF. "Future Food Production System Development Pulling From Space Biology Crop Growth Testing in Veggie." 33rd Annual Meeting of the American Society for Gravitational and Space Research, Seattle, WA, October 25-28, 2017.</p> <p>33rd Annual Meeting of the American Society for Gravitational and Space Research, Seattle, WA, October 25-28, 2017. , Oct-2017</p>
Articles in Peer-reviewed Journals	<p>Urbaniak C, Massa G, Hummerick M, Khodadad C, Schuerger A, Venkateswaran K. "Draft genome sequences of two Fusarium oxysporum isolates cultured from infected Zinnia hybrida plants grown on the International Space Station." Genome Announc. 2018 May 17;6(20):e00326-18. https://doi.org/10.1128/genomeA.00326-18 ; PubMed PMID: 29773617; PubMed Central PMCID: PMC5958250 , May-2018</p>
Dissertations and Theses	<p>Burgner SE. "Physiological and Growth Characteristics of Brassica rapa 'Tokyo Bekana' Grown within the International Space Station Crop Production System." Thesis, Purdue University, August, 2017.</p> <p>https://docs.lib.purdue.edu/dissertations/AAI10607690/ , Aug-2017</p>