Fiscal Year:	FY 2016	**Task Last Updated:**	FY 07/26/2016
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		
PI Email:	gioia.massa@nasa.gov	**Fax:**	FY
PI Organization Type:	NASA CENTER	**Phone:**	321-861-2938
Organization Name:	NASA Kennedy Space Center		
PI Address 1:	ISS Ground Processing and Research		
PI Address 2:	Mail Code UB-A-00		
PI Web Page:			
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:**	08/31/2018
No. of Post Docs:	0	**No. of PhD Degrees:**	
No. of PhD Candidates:		**No. of Master' Degrees:**	
No. of Master's Candidates:	2	**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA JSC
Contact Monitor:	Douglas, Grace	**Contact Phone:**	
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Flight Program:	ISS		
Flight Assignment:	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:	CoInvestigator Alexandra Whitmire has been changed to Thomas Williams – Feb. 2016 ; CoInvestigator Rob Ploutz-Snyder has been changed to Millennia Young– July 2016.		
COI Name (Institution):	Douglas, Grace Ph.D. (NASA Johnson Space Center) Hummerick, Mary M.S. (Qinetiq North America, Inc.) Mitchell, Cary Ph.D. (Purdue University) Morrow, Robert Ph.D. (Orbital Technologies Corporation) Wheeler, Raymond Ph.D. (NASA Kennedy Space Center) Young, Millennia Ph.D. (NASA Johnson Space Center) Williams, Thomas Ph.D. (Wyle Laboratories)		
Grant/Contract No.:	Internal Project		

Performance Goal No.:	
Performance Goal Text:	
Task Description:	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. 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. 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. Specific aim 3: Perform hazard analysis, develop plans for minimizing microbial hazards, and screen flight-grown produce for potential pathogens.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	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.
	Since the grant initiation on 09/01/2015 significant progress has been made. As part of the preliminary research leading to the start of the grant, Kennedy Space Center (KSC) personnel completed the down selection of leafy greens cultivars and tomato cultivars for testing and selected 'Tokyo bekana' Chinese cabbage and 'Red Robin' tomato as the best candidates for ILSRA testing and for growth in Veggie on the ISS. These down selections were based on growing eight leafy green candidates and six tomato candidates under ISS-relevant controlled environment conditions of temperature, relative humidity, and elevated CO2. Unlike the Veggie system, plants were grown in peat-based potting substrates with both controlled-release and liquid fertilizer, and plants were grown under broad-spectrum fluorescent lamps. Plants were assessed for growth habit, yield of edible biomass, and nutrient levels of edible biomass focusing on specific nutrients of interest for space (e.g., potassium, magnesium, zeaxanthin, lutein, and antioxidants). Cultivars were down-selected and the top subsets were regrown and samples sent to NASA Johnson Space Center (JSC) for organoleptic analysis which, when coupled with the other data, led to the selection of the top candidates. Numerous graduate student candidates were interviewed at Purdue University and a Masters Student, Sam Burgner, was selected to work on this project with his tenure beginning in August, 2015. Sam travelled to KSC in October, 2015, and learned the construction and operation of the Veggie analog systems. Planning and consultation among KSC, Purdue, and ORBITEC personnel along with Florikan fertilizer partners was carried out in September-November, 2015 to determine the optimum fertilizer formulations to test with selected crops. Based on the expertise of the team it was decided that Chinese cabbage would be tested with three different formulations of Nurtricote 18-6-8 controlled release fertilizer. Testing would examine the release rate of this fertilizer, with the three test scenarios being A) 180-day release, B) a 2:1 ratio of 180-day release to 100-day release, and C) a 1:1 ratio of 180-day release to 100-day release. For tomato the same release rates would be tested but instead of testing the 18-6-8 (N-P-K) fertilizer, the Nutricote 14-4-14 will be tested. Our fertilizer consultants recommended that equal levels of nitrogen and potassium would be best for a fruiting crop like tomato, while a leafy crop like Chinese cabbage, needs more nitrogen. In addition, tomatoes require extra calcium to prevent physiological disorders in the fruit, so the team decided to supplement the N-P-K fertilizer with calcium carbonate and calcium nitrate. Light treatments were also selected, which included: A) 90% Red, 10% Blue, B) 70% Red, 30% Blue, C) 50% Red, 50% Blue, and D) a split treatment of 90% Red, 10% Blue followed by a change to 50% Red, 50% blue. In all cases, the Red and Blue light would be provided with LEDs (light emitting diodes), similar to the lighting system in Veggie. For the split treatment, the team decided to switch from high red to equal red: blue light after the plants had completed ¾ of their growth. The goal of the split treatment is to enhance nutrients prior to harvest. Chinese cabbage is scheduled to grow for 28 days and tomatoes are scheduled for 3 months. ORBITEC outfitted six Biomass Production System for Education (BPSe) Veggie analog systems with LED lights and shipped them to Purdue University where they were set up in controlled environment growth chambers. Similarly, six BPSe systems with fluorescent lights belonging to Kennedy Space Center were retrofitted with LED lights and returned to KSC. These were long lead items and arrived at KSC in late December 2015 and at Purdue in January 2016. Systems are larger than the veggie on ISS but are similarly adjustable in height, so lights can be maintained at a set distance above plants and this height can be adjusted upwards as plants grow. For preliminary trials lights were maintained at 10 cm above plants. These BPSe systems were installed and calibrated at both locations in January and February of 2016. Calibration involved extensive light mapping at defined points beneath the light caps at the proposed light settings. Because BPSe units have slider controls for the light intensity rather than digital controls, these set points needed to be established. Quantum light meters and spectroradiometers were used for light mapping and for precise calibration of

Task Progress:	each light system. The units were also mapped out to ensure that as many plant rooting pillows as possible could be placed in each. The systems allowed 12 plant pillows for Chinese cabbage containing 180 mL of substrate and 6 of the larger pillows for tomato containing 360 mL of substrate. The first growth trial with Chinese cabbage was initiated at the week of 2/29-3/4/16 at both KSC and Purdue. This followed several weeks of preparation of the Veggie analog growth system and analog plant pillow manufacturing. Trial 1 was conducted with the four light treatments and three fertilizer treatments with 144 total plants grown between KSC and Purdue. Plants were grown for 28 days and photographed, then harvested. Harvested plant material was measured, weighed, assessed for chlorophyll content and leaf area, and then either frozen for chemical analysis or processed for microbiological assessment. Frozen plants were freeze dried and tissue was ground and extracted. Plant pillows were also oven dried to obtain pH and conductivity readings of the substrate. After a short period for cleaning a second trial was conducted with re-randomization of the light and fertilizer treatments within each BPSe unit. The light treatments that had previously been replicated at Purdue were replicated at KSC in trial 2. Plants and pillows were treated similarly. Chemical analysis of these trials is still underway. KSC is analyzing specific elements of interest to astronaut health, and measurement of antioxidants, phenolics, and anthocyanins. Purdue University is conducting analysis of nitrates and nitrites. KSC also conducted microbiology assays for aerobic plate counts and total yeasts and molds from a subset of plants. Microbiological results from the first two trials indicated larger microbial loads than expected. Expectations were based on microbial levels previously observed with this species in testing for the Veg-03 demonstration flight in Veggie. Data are being compiled for statistical analysis at this time. Results will allow us to down select from the 12 possible combinations of fertilizer and light to a goal of the top four or five options for future assessment. The next sets of assessments will be organoleptic evaluation at JSC and the costly Vitamin K analysis at an outside lab. During later growth and at final harvest, some symptoms of stress were noted in the Chinese cabbage plants grown in the BPSe units. This stress had not been observed in prior growth studies, and our hypothesis is that this cultivar of Chinese cabbage suffers in response to narrow spectrum radiation. Symptoms observed included chlorosis and speckled bleaching of leaves. The severity of symptoms appeared to vary with light treatment but not with fertilizer treatment. A scoring guide was developed to allow quantification of stress responses at the different locations. Treatments with higher levels of red light (90% Red, 10% blue and the split treatment) appeared to have the highest proportion of stressed leaves. Additionally stress responses increased dramatically in all treatments between day 22 and day 28 of growth. It was decided to hold further trials of Chinese cabbage pending chemistry, statistical analysis, and further investigation into plant stress, and to instead conduct a trial of tomato in four systems both at Purdue and KSC. In the remaining two systems at Purdue troubleshooting efforts will attempt to diagnose the causes of plant stress. These tests are ongoing, focusing on light intensity levels and looking at substituting other wavelengths for red light. One hypothesis is that light of a lower intensity but spread out over a longer duration to provide the same daily light integral (DLI) might prevent the observed stress. In the remaining two systems at KSC, the focus will be to conduct microbiological testing of Chinese cabbage. These tests are also on-going and our team is looking at seed surface sterilization and media sterilization as methods to reduce overall microbial loads. These sterilization techniques are used for spaceflight and will be used during future flight experimentation, so isolating the critical control points at this time is the goal of this testing. Meanwhile, ORBITEC has prepared their plant growth rooms for subsequent larger growth trials. These rooms will be used to conduct large capacity growth studies of selected light and fertilizer conditions, where harvested produce will be shipped to JSC for organoleptic evaluation or freeze dried and ground for Vitamin K evaluation. Initial preparations are underway for flight tests of these crops following ground, down-selection of fertilizer and light. JSC behavioral health and performance Co-I Tom Williams is assessing appropriate crew surveys and IRB (Institutional Review Board) requirements. The KSC Veggie team has begun coordinating with the Human Research Program (HRP) to start planning the on-orbit testing. A second Veggie unit will be launched to the ISS and co-located near the current unit, which will allow side by side testing of two independent light treatments in ISS. This is a significant improvement on the initially proposed subsequent testing because environmental conditions for the two treatments will be identical. The Chinese cabbage test has been preliminarily planned as Veg-04, with the tomato test book kept as Veg-05. Due to issues with the current Veggie watering system providing insufficient water for longer duration crop studies it has been decided that Veg-04 and Veg-05 are on hold until a new Veggie watering system capable of sustaining the plants can be developed.
Bibliography Type:	Description: (Last Updated: 10/26/2023)
Abstracts for Journals and Proceedings	Massa GD, Hummerick ME, Douglas GL, Wheeler RM. "Weaving Together Space Biology and the Human Research Program: Selecting Crops and Manipulating Plant Physiology to Produce High Quality Food for ISS Astronauts." Symposium on translational research between SLPS and HRP, 31st Annual Meeting of the American Society for Gravitational and Space Research, Alexandria, VA, November 11-14, 2015. 31st Annual Meeting of the American Society for Gravitational and Space Research, Alexandria, VA, November 11-14, 2015. , Nov-2015
Articles in Peer-reviewed Journals	Massa GD, Wheeler RM, Morrow RC, Levine HG. "Growth chambers on the International Space Station for large plants." Acta Hortic. 2016 May;1134:215-22. http://dx.doi.org/10.17660/ActaHortic.2016.1134.29 , May-2016