Fiscal Year:	FY 2017	**Task Last Updated:**	FY 07/11/2017
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:	1	**No. of Master' Degrees:**	1
No. of Master's Candidates:	1	**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:	8	**Monitoring Center:**	NASA JSC
Contact Monitor:	Douglas, Grace	**Contact Phone:**	
Contact Email:	grace.l.douglas@nasa.gov		
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:	August 2017: LaShelle Spencer and Matt Romeyn have been added as Co-Investigators as of August 23, 2017. CoInvestigator Thomas Williams has been changed to Alexandra Whitmire – Jan. 2017.		
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) Whitmire, Alexandra M. Ph.D. (Wyle Laboratories) Spencer , LaShelle M.S. (NASA Kennedy Space Center) Romeyn, Matt M.S. (NASA Kennedy Space Center)		
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. 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 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 on the impact of light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, 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.
Task Progress:	Crop Testing Chinese cabbage: Following down selection to a top leafy green ('Tokyo bekana' Chinese cabbage) and tomato ('Red Robin' dwarf tomato) varieties, testing was conducted using analog Veggie growth systems using the four light treatments and three fertilizer treatments selected. Plants were grown in analog Veggie pillows using a mixture of arcillite and vermiculite substrate. Although plants were grown under identical conditions in both locations, differences in growth between crops grown at the different locations were large and these tended to confound the light and fertilizer variables. Under ISS and Veggie-relevant conditions, however, the 'Tokyo bekana' Chinese cabbage exhibited moderate to severe stress symptoms. Symptoms included yellowing (chlorosis) and necrotic lesions on leaves. This symptomology led Purdue team members to investigate the underlying causes of these stress responses, while Kennedy Space Center (KSC) team members focused on trying to mitigate the response via fertilization. A series of tests at Purdue attempted to determine the sources of this stress. Chemistry of plant samples from the first two pillow tests indicated high levels of Manganese in plant tissues. Tests comparing rinsed and un-rinsed arcillite attempted to determine if these excessive levels were due to minerals leaching from the substrate. Additional testing was performed with different particle sizes of arcillite. Data from these tests showed no significant differences in plant growth in response to particle size or substrate rinsing. Additional testing conducted at Purdue substituted green lighting for red lighting and canopy separation distance from the light cap. Neither approach positively impacted plant growth, nor reduced observed stress responses. While the Purdue team worked to track down the source of Chinese cabbage stress, the KSC team attempted to mitigate that stress via fertilizer supplementation. For this reason, the most stress-inducing lighting treatment of 90% Red: 10% Blue was used. Regardless of treatment Chinese cabbage still showed signs of stress. The Purdue team then conducted studies growing plants under either 600 ppm CO_2 or elevated CO_2 at 2800 ppm, the conditions found on the ISS. In addition to growing plants for 28 days under these conditions, they also swapped trays of plants between conditions at 14 days and 21 days. They found that not only was plant growth better when plants were grown for longer under 600 ppm but damage to leaves was also directly dependent on receiving lower CO_2, especially during the last two critical weeks of growth. These results led to the examination of photosynthetic responses of this crop to different CO_2 levels. When grown under three different CO_2 levels of 450, 900, and 1350 ppm, Chinese cabbage showed large differences in many growth parameters, including fresh and dry masses of tissues, with the best growth seen at the lowest CO_2 level. This response is quite different than many other plants studied and makes this crop interesting physiologically. Note, most so-called C3 photosynthesis plants typically show increased photosynthetic rates when CO_2 is elevated from ambient (Drake et al., 1997). This feature, however, likely indicating the stress observed under the elevated CO_2 levels of ISS, makes this plant unsuitable to grow in the Veggie chamber. For this reason, Mizuna was selected as the crop for subsequent spaceflight experimentation. Mizuna: Mizuna showed similar yield to Chinese cabbage in PONDS (Passive Orbital Nutrient Delivery System) tests but had very few indications of stress. Earlier crop selection testing also indicated that Mizuna was an excellent candidate for spaceflight from a nutritional and organoleptic perspective (Massa et al., 2015). In addition, mizuna has been grown successfully in space before in the Russian Lada chamber on ISS, giving us more confidence in moving from Chinese cabbage to mizuna (Sugimoto et al., 2014). Initial tests with Mizuna used older seeds. The crop grew very robustly in the PONDS analog watering system with Veggie-analog lighting and testing on this crop with different lighting treatments is underway. Moving forward testing will continue with Mizuna which will be the crop grown in VEG-04 and 'Red Robin' which will be grown in the VEG-05 tests. Dwarf tomato: KSC and Purdue conducted one full trial of tomato plants in rooting pillows. Results indicated good fruit production but with large amounts of variability in response due to location of testing. Also, plants demonstrated stress responses including stunting, nutrient defects, leaf curling, purpling of leaf and stem, and leaf senescence and abscission. Some of these impacts may have been due to the crop variety, some to the cultivation conditions, and some to the environment. Tomatoes are currently being grown in analog PONDS systems with an augmented fertilizer composition at KSC, and similar testing is starting in the larger growth rooms at SNC/ORBITEC. This experiment will be harvested in August, 2017. In addition to the fertilizer comparison, pollination methods are being tested, with a small soft brush being compared to manual plant shaking. Watering System: During the past year, the Veggie team has modified the Veggie watering system. The original system of plant pillows with a wicking reservoir was found to provide insufficient water to the plants (Massa

et al., 2017) in earlier flight testing. Because of this the Veggie team has selected the PONDS (Passive Orbital Nutrient Delivery System) as the next watering system which will be used for the upcoming VEG-04 and VEG-05 flights for this project. The contract for the development of this hardware required for pre-flight testing and flight experimentation has been awarded to TechShot, and they have subcontracted out to Tupperware for these units. Our project team has had input into the design requirements for this hardware. Preliminary units are scheduled to arrive in Nov. 2017 for the initial science verifications tests with the Mizuna crop.

Crew assessments: Questionnaires to survey astronaut mood in response to plant growth, as well as organoleptic analysis ratings for on-orbit produce consumption have been developed and were submitted to the Johnson Space Center (JSC) eIRB process. Questions will be asked of all USOS crew members that will fly during the time that plants will be grown on ISS. Organoleptic evaluations will be conducted by crew who are available to taste produce during harvest events.

Flight software development: Firmware modifications for the Veggie system controller were completed during the first project period. During the project period covered by this report the new firmware was tested on flight-like Veggie units and will be loaded on four ground Veggie units sent to KSC and one unit maintained in house at SNC/ORBITEC. The new firmware will be loaded on the two Veggies on the ISS when crew time is available. The firmware modifications changed the red and blue LED light intensity control method. There was interest expressed by KSC to make this modification for green LEDs also. This was determined by SNC/ORBITEC to be feasible but it has not been determined if it will be done at this time. It may be implemented at a later date. Once the new firmware is fully functional in all ISS Veggie units this task will be complete.

Preparation for Flight Experimentation: A second Veggie unit (Veggie SN 001) launched to the ISS aboard the Orbital ATK space station resupply mission (OA-7) on April 18th, 2017 from Kennedy Space Center. This unit is planned to be installed in the Columbus module EXPRESS (EXpedite the PRocessing of Experiments for Space Station) rack containing the original ISS Veggie (SN 002) in late summer or early fall of 2017. The two units will be used simultaneously for the VEG-04 and VEG-05 experiments to perform side-by-side testing with different light spectra for growth of Mizuna and Dwarf tomato, respectively.

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