Fiscal Year:	FY 2019	**Task Last Updated:**	FY 05/24/2019
PI Name:	Xiao, Hang Ph.D.		
Project Title:	Vitamins B1 and K Degradation in Spaceflight Foods: Establishment of Prediction Models and Prevention Strategies		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Space Human Factors Engineering		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HHC**:Human Health Countermeasures		
Human Research Program Risks:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	hangxiao@foodsci.umass.edu	**Fax:**	FY
PI Organization Type:	UNIVERSITY	**Phone:**	413-545-2281
Organization Name:	University of Massachusetts		
PI Address 1:	Food Science		
PI Address 2:	100 Holdsworth Way		
PI Web Page:			
City:	Amherst	**State:**	MA
Zip Code:	01003-9282	**Congressional District:**	1
Comments:			
Project Type:	Ground	**Solicitation / Funding Source:**	2013 HERO NNJ13ZSA002N-Crew Health (FLAGSHIP & NSBRI)
Start Date:	08/11/2014	**End Date:**	02/28/2019
No. of Post Docs:	0	**No. of PhD Degrees:**	2
No. of PhD Candidates:	4	**No. of Master' Degrees:**	0
No. of Master's Candidates:	2	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NASA JSC
Contact Monitor:	Douglas, Grace	**Contact Phone:**	
Contact Email:	grace.l.douglas@nasa.gov		
Flight Program:			
Flight Assignment:	NOTE: End date changed to 2/28/2019 per NSSC information (Ed., 4/12/18) NOTE: Element change to Human Health Countermeasures; previously Space Human Factors & Habitability (Ed., 1/18/17)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Decker, Eric Ph.D. (University of Massachusetts, Amherst) He, Lili Ph.D. (University of Massachusetts, Amherst) Liu, Anna Ph.D. (University of Massachusetts, Amherst) McClements, David Ph.D. (University of Massachusetts, Amherst) Peleg, Micha D.Sc. (University of Massachusetts, Amherst)		
Grant/Contract No.:	NNX14AP32G		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Currently, shelf stable foods that do not require refrigeration or freezing are the sole source of nutrition for the spaceflight crew. It is therefore crucial that these foods provide adequate nutrition to support the crew throughout the shelf life of the product. However, knowledge is currently lacking on the degradation kinetics of essential vitamins (e.g., vitamins B1 and C) during processing and storage of spaceflight foods. To address this critical knowledge gap, this project aims to measure vitamins B1 and C degradation kinetics and use this information to establish robust computational models that are user friendly to predict vitamin stability in spaceflight foods during processing and storage. Our central hypothesis is that: (i) Based on a systematic investigation of the degradation kinetics of vitamins B1 and C, computational models can be developed to predict vitamin degradation during processing and storage of spaceflight foods. Our main approach is therefore to identify the influence of food processing, food matrix composition, storage conditions, and other factors (e.g., pH) on the degradation kinetics of vitamins B1 and C. Then we will use this knowledge to establish robust models and guiding principles to predict and prevent degradation of these vitamins.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	A considerable amount of research has been conducted on the stability of essential vitamins including vitamins B1 and C in different food systems. However, a detailed understanding is lacking on the degradation of essential vitamins under the unique conditions experienced by spaceflight foods. The significance of the proposed research is that it will provide fundamental knowledge that is currently lacking about the roles of food processing, food matrix characteristics, and storage conditions on the degradation kinetics of vitamins B1 and C in spaceflight foods. A particularly innovative aspect of the project is that it utilizes robust mathematical modeling to simulate and predict degradation kinetics of essential vitamins. It also can help develop guiding principles to stabilize these vitamins in spaceflight foods. Successful completion of this project will provide critical information that can be used to produce more nutritious shelf stable spaceflight foods to better maintain health & wellness of spaceflight crew.
Task Progress:	We have concluded our 2-year storage study in successful monitoring, modelling, and subsequent predicting of vitamin B1 and vitamin C content within several thermally processed and freeze-dried versions of NASA-provided recipes: brown rice, split pea soup, and BBQ beef brisket for vitamin B1, and strawberries, sugar snap peas, and rhubarb applesauce (± 0.5 units pH) for vitamin C. At the conclusion of the 2-year storage lifetime, vitamin B1 was generally most stable in thermally processed brown rice, less so in split pea soup, and drastically less in BBQ beef brisket, based on NASA's formulation. Although degradation of B1 was slowest and less influenced by temperature in the thermally processed rice, B1 was more abundant in the split pea soup product at the end of the 2-year storage period at any temperature tested, compared to the more stable brown rice product. B1 in BBQ beef brisket was undetectable at the end of the storage period at 37°C storage and approaching an undetectable limit for the two other storage temperatures. The process of freeze-drying these foods resulted in unique differences of vitamin B1 stability compared to the non-freeze-dried versions. Freeze-dried brown rice demonstrated better resistance to vitamin B1 degradation at higher temperatures, but a diminished protective effect in refrigeration conditions, comparing the final vitamin B1 concentrations between thermally processed and freeze-dried brown rice. This same trend (of decreased temperature dependence on degradation rate) was observed in the split pea soup, but not in the BBQ beef brisket, where differences in food matrix composition and chemistry are though to play a role on vitamin B1 degradation differentially. Vitamin B1 was also quantified in brown rice, split pea soup, and BBQ beef brisket that were either thermally processed or freeze-dried, and then stored at either -20°C or -80°C for 2 years as a quality control measure. For vitamin C, freeze-drying preserved the vitamin better throughout all foods under all temperatures except 37°C. The degradation rate was the most noticeable difference because in many cases freeze-drying caused the food to approach a zero residual concentration quicker than the thermally processed foods. However, the freeze-drying concentration started with a higher vitamin C amount. As long as the vitamin C was detectable or had a nonzero concentration, freeze-drying still had more vitamin C than the thermally processed foods. This finding stressed how the initial concentration and an elevated storage temperature can influence vitamin C degradation. Sugar snap peas had many bewildering findings for the thermally processed and freeze-dried foods. Specifically for thermally processed sugar snap peas, the vitamin concentration considerably declined for all temperatures and was undetectable for all temperatures before the end of the two-year storage study. The stability was better during freeze-drying, but a sharp drop occurred at 12 mo for 20°C freeze-dried sugar snap peas, which seemed valid considering the remaining time points stabilize near that concentration. The cause of the dropped has yet to be determined, and we assume there had to be some form of phenomenon that increased vitamin C dissolved oxygen leading to a more rapid degradation. All the acidic foods, all rhubarb applesauce foods and strawberries had higher stability during thermal processing and freeze-drying, especially freeze drying where 4 and 20°C had negligible degradation during the two-year storage study. However, rhubarb applesauce at pH4 experienced a more rapid degradation rate due to the increased pH level. There was a similar trend with rhubarb applesauce at pH3, except reduced degradation rate, due to the lower pH level. Testing four previously established models (generated from vitamin content measures made following 37°C and 20°C storage for 3, 6, 9, or 12 months and 4°C storage for 4, 8, and 12 months) by comparing experimentally measured vitamin content and the model-predicted values at each relevant time point, <10% prediction error was observed at 2 years using data from 9 and 12 months of storage for vitamin B1 in the majority of food products. In two cases, <15% error was observed at the conclusion of storage. For vitamin C, models developed using data of low acid foods produced the lowest % error in predicting final vitamin C content. High acid foods were observed developing an emerging resistance to degradation late into the storage lifetime which caused divergence between original models and the experimental trend. By adding a factor into our models, representing significant non-zero asymptotic behavior, vitamin C predictive models improved significantly. Following inclusion of this factor, vitamin C predictive models were within 10% of the experimental trend at 2 years of storage. Food products were also differentially thermally processed and measured for their vitamin content. The time-temperature profiles from each thermal process (conducted in triplicate and probed in quadruplicate) were recorded and used together with the resulting vitamin concentration to produce predictive models based on a non-isothermal version of the Endpoints Method used above. For vitamin B1 modelling, <5% error was observed across the board. After analyzing vitamin C concentration before and after thermal processing and thereby determining the kinetic degradation parameters of each food, our model demonstrated less than 9% residual average difference between experimental and

predicted concentration values showing a 2.7% difference for rhubarb applesauce and a 7.8% difference for sugar snap peas.

In conclusion, we were able to quantify vitamin B1 and C in several NASA formulations prior to and following thermal processing, as well as prior to and during long-term storage for foods which were thermally stabilized or freeze-dried. The benefit from freeze-drying was assessed, and revealed differences based on the food matrix. We successfully produced predictive models that were able to generate predictions of vitamins B1 and C content at 2 years, generated from data gathered during the first year of the storage lifetime of all foods. Modelling vitamin B1 loss during thermal processing by the non-isothermal version of the Endpoints Method provided estimations within 5% error, lending promising results for the utilization of this model in food processing environments for the development of optimal thermal processes as well as estimating nutritional destruction by such processes without cumbersome analysis. Vitamin C degradation in foods during thermal processing was also highly modellable, producing estimations with <5% error in rhubarb applesauce, <10% error in sugar snap peas, and 12% error or less in strawberries.

Bibliography Type:	Description: (Last Updated: 09/02/2019)
Articles in Peer-reviewed Journals	Goulette TR, Zhou J, Dixon WR, Normand MD, Peleg M, McClements DJ, Decker E, Xiao H. "Kinetic parameters of thiamine degradation in NASA spaceflight foods determined by the endpoints method for long-term storage." Food Chem. 2020 Jan;13;302:125365. Epub 2019 Aug 13. https://doi.org/10.1016/j.foodchem.2019.125365 ; PubMed PMID: 31442703 , Jan-2020