Fiscal Year:	FY 2017	**Task Last Updated:**	FY 06/06/2017
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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
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Human Research Program Risks:	None		
Space Biology Element:	None		
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Space Biology Special Category:	None		
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Zip Code:	01003-9282	**Congressional District:**	1
Comments:			
Project Type:	Ground	**Solicitation / Funding Source:**	2013 HERO NNJ13ZSA002N-Crew Health (FLAGSHIP & NSBRI)
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No. of Master's Candidates:	2	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:	Douglas, Grace	**Contact Phone:**	
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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:			
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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 the 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 five-years of 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:	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 parameters that effect degradation of essential vitamins (e.g., vitamins B1 and C) during the processing and storage of specific spaceflight foods. To address this critical knowledge gap, this project aims to determine how vitamins B1 and C degrade, express such degradation in mathematical terms, and use this information to establish easy-to-use computational models that predict vitamin content in spaceflight foods during processing and five-years of storage. We sought to obtain all necessary ingredients to produce large quantities of food that could then be made shelf-stable for long periods of time, if not indefinitely, by thermal stabilization (destruction of spoilage organisms by heat) and by freeze drying (inactivation of spoilage organisms by low water activity). These foods would be stored in varying temperature conditions so that when the vitamin content is measured, we would be able to understand the effect of temperature on the rate at which our target vitamins degrade. This effect would be discerned using a mathematical model which would then be used to make accurate predictions about the vitamin content in that food at times and temperatures not yet determined. Through this process we can also gain insight into the effect of food matrix properties and water activity on the degradation of vitamins. We also studied the nature of vitamin degradation during thermal stabilization, by recording the temperature of the process, measuring the vitamin content at the end of the process, and using a model that can accept this type of data to determine the degradation behavior. We are currently approaching the first year of progress in relation to having processed, stored, analyzed, and modeled foods containing our vitamins of interest. At this same time last year, brown rice, split pea soup, BBQ beef brisket, rhubarb applesauce (varying in natural pH ± 0.5), strawberries, and sugar snap pea were produced to specifications according to their NASA recipe. In total, more than 3,000 pouches of food were made, entered into a tracking database, and stored. More than 100 lbs of brown rice, nearly 200 lbs of split pea soup, around 200 lbs of beef brisket, 130 lbs of strawberries, 400 lbs of rhubarb applesauce, and more than 100 lbs of sugar snap peas were produced and either thermally stabilized in retort according to their respective recipes or prepared for freeze drying in order to assess the degradation of their respective vitamin of interest. We have maintained stored wet and freeze-dried samples for nearly a year, performing regular analysis on stored samples for use in modeling. Explanation of the specific storage conditions, analysis, and modeling process is below. All vitamin analysis to date has been performed and vitamin retention has been calculated for both vitamin B1 and C. Preliminary modeling has been conducted using data from 37°C and 20°C stored food samples at 3 months of storage and 4°C stored samples at 4 months to reveal the parameters that the model utilizes to describe the degradation behavior of the vitamins of interest. These parameters were successfully used to build a model of the vitamin's retention over time, allowing for predictions of vitamin retention at time points already measured, to gauge accuracy of the model, as well as time points in the future, to be made. To demonstrate the strength of the model during interpolation, data from 37°C stored samples at 3 months and 4°C stored samples at 4 months was used to formulate a model that would then predict the vitamin content of 20°C stored samples at 3 and 6 months. This proved successful in producing a low degree of error between the predicted vitamin retention values and the real values that were measured. The project remains a success, as processing, analysis, and modeling proved not only possible but sufficient to make some early conclusions. We are able to use model information to learn and anticipate how certain parameters influence the model's predictions. We will soon be able to see, once data begins to come in for the end of the year, which isothermal model construction produces the most accurate portrayal of degradation throughout the food's lifetime. As mentioned above, the model produces the smallest error, and therefore most accurate predictions, when it is being used to interpolate temperature and time points. In terms of freeze-dried foods, all vitamin analysis to date has been performed and vitamin retention has been reported as well. We are in the process of analyzing vitamin content for 4 months for foods where vitamin B1 is of interest (therefore modeling is not yet available) but is complete in vitamin C foods. Regardless, vitamin retention was plotted against thermal processed retentions so that vitamin retention improvement due to drying, if any, could be assessed. The exact effect of drying on vitamin degradation at this point does not seem to conform to a specific paradigm. There needs to be more points to analyze to better understand this phenomenon. In vitamin C foods, there are enough data to determine initial degradation parameters via modeling, but not enough data time points to compare predictions with experimental values.

Freeze drying, at this stage, provided interesting results. The improvement to thiamine's degradation after drying was not immediately evident, and will require more analysis points before the true effect can be discerned. It is possible that the process of freezing, drying, and repackaging led to some portion of the results observed by destruction or conversion of the compound. Data at 4°C for 4 months and beyond are expected to be gathered soon, wherein modeling can then be performed and the degradation parameters can be gathered. This will allow us to directly compare these parameters between wet and dried products' thiamine degradation.

An additional experiment was conducted to study the effects of thermal processing conditions on vitamin degradation. We utilized a related method to our isothermal degradation parameters model that we can utilize varying temperature data (as opposed to a static storage temperature) to find kinetic parameters, which we can gather from our retort vessel. Our strategy was to produce three distinct temperature processes for each NASA recipe (low temperature-long time, moderate temperature-moderate time, and high temperature-short time), record the time and temperature data throughout the process, and conduct analysis on the vitamin content after processing, as the model still only requires vitamin concentration at the end of the process. Then, two of the three temperature profiles are entered into the model in order to produce values describing the vitamin degradation. These values are then maintained while one of the two temperature profiles are changed out with the third. The resulting degradation prediction is compared to the real value. We demonstrated that this method of constructing this model produces predictions with less error on average than the static storage model, with even less data.

Although at the outset, it would seem that building a model that is able to reveal the kinetic parameters of degradation during a non-isothermal process with only two data points would be quite difficult, it actually provided a clearer picture of the degradation in processing compared to the degradation in storage. The error in this model was typically lower than that of the stored recipes, which is a promising result. However, the results need to be repeated with a replicate experiment, which will be conducted soon. Care will be taken to procure the same exact recipe as in the first case.

We have also worked on two new publications which can offer insights on where to take this project in the future, specifically about accounting for the total vitamin C content as opposed to merely ascorbic acid:

[1] Peleg, M., Normand, M. D., Dixon, W. R. and Goulette, T. R. 2017. Modeling the degradation kinetics of ascorbic acid. Critical Reviews in Food Science and Nutrition. (In press – available on line)

[2] Peleg, M., Normand, M. D. and Corradini, M. G. 2017. A new look at kinetics in relation to food storage. Annual Reviews in Food Science and Technology 8:135-153.

Overall, the progress of the project has been good. Constant pull dates for analysis can prove demanding at times, but possible. However, we did choose to maintain reporting "time" in terms of days rather than months, in order to allow more granularity in modeling if a day or two passes before analysis is able to be done (although this has not yet occurred). There is still much more data to collect and process, which will shed light on the rest of the modeling that needs to be done.

Bibliography Type:	Description: (Last Updated: 09/02/2019)
Articles in Peer-reviewed Journals	Peleg M, Normand MD, Dixon WR, Goulette TR. "Modeling the degradation kinetics of ascorbic acid." Critical Reviews in Food Science and Nutrition. 2018 Jun 13;58(9):1478-94. https://doi.org/10.1080/10408398.2016.1264360 ; PubMed PMID: 27892705 (Reported originally in June 2017 as "Published online: 28 Nov 2016.") , Jun-2018
Articles in Peer-reviewed Journals	Peleg M, Normand MD, Corradini MG. "A new look at kinetics in relation to food storage." Annual Reviews in Food Science and Technology. 2017 Feb 28;8:135-53. https://doi.org/10.1146/annurev-food-030216-025915 ; PubMed PMID: 28068487 , Feb-2017