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Project Title:	Vitamins B1 and K Degradation in Spaceflight Foods: Establishment of Prediction Models and Prevention Strategies		
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Space Biology Special Category:	None		
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Comments:			
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No. of Bachelor's Candidates:	2	Monitoring Center:	NASA JSC
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Key Personnel Changes/Previous PI:			
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Task Description:	<p>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 use this knowledge to establish robust models and guiding principles to predict and prevent degradation of these vitamins.</p>
Rationale for HRP Directed Research:	<p>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.</p>
Research Impact/Earth Benefits:	<p>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 affect 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.</p> <p>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.</p> <p>Currently, we are near the end of our 2 year storage study. All vitamin C and B1 analysis to date has been performed and vitamin retention has been reported. Time-grouped modelling has been conducted using data from 37°C and 20°C stored samples at 3, 6, 9, or 12 months with 4°C stored samples at 4, 8, and 12 months to reveal the parameters that describe the degradation behavior of the vitamins of interest. We collected a plethora of kinetic parameters, which are “kTref,” the degradation rate constant, and “c,” temperature sensitivity term. These parameters are the degradation rate constant “kTref” and temperature sensitivity term “c.” These terms were used to build a model of the vitamin’s retention over time for up to 2 years of storage.</p> <p>Overall, the thiamine (vitamin B1) stability in the brown rice (BR) and pea soup (PS) product seemed high, while in the beef brisket (BB) the vitamin seemed less stable, even at low storage temperatures. Also, the original vitamin content in the brown rice and pea soup recipes were very similar. Throughout analysis, beef brisket was noted to have a drastic range of texture and compositional variation, possibly due to heterogeneous fat deposition and muscle density. Storage at 37°C for 18 months has demonstrated drastically accelerated vitamin degradation across all foods, leading to the elimination of detectable thiamine in beef brisket.</p> <p>For ascorbic acid (vitamin C), there has been a consistent degradation in all foods; however, not all time points decrease in vitamin content. Most noticeable at 4°C in strawberries (ST) and at 20°C in rhubarb applause at pH 3 (RAPH3). When standard deviation is taken into consideration, it is prevalent that the degradation is low among those timepoints. Another noticeable phenomenon is sugar snap peas (SP) rapid degradation for 4, 20, and 37°C. Both 20 and 37°C SP vitamin C content was undetectable at 15 mo and undetectable at 20 mo for 4°C. The food matrix complexity and higher pH most likely led to the rapid degradation. It is also important to note that the limit of detection was limited due to the lack of separation at lower concentration in sugar snap peas. Most likely, small residual amounts of vitamin C could be remaining, but are not detectable using the current method and prior vitamin C analysis conditions for SP.</p> <p>Additionally, all vitamin analysis to date has been performed and vitamin retention has been reported for freeze dry foods. We are in the process of analyzing vitamin content for 18 months. It is evident that the lower water content had a significant role on improving vitamin C stability for all temperatures. With vitamin C foods, 37°C was much more rapid during freeze drying compared to retort thermoprocessing. For both food processes, modelling was utilized and a variety of predictive curves were constructed using different experimental timepoints kTref and c values.</p> <p>The project remains a success, as processing, analysis, and modelling proved not only possible but sufficient to make determinations about vitamins B1 and C’s degradation behaviors. We are able to use model information from 3 to 12 months of storage to learn and anticipate how certain sets of data influence the model itself. As shown above, the model produces the smallest error, and therefore most accurate predictions, when the data being used is slightly delayed (after 3 or 4 months). However, these models from 3 and 4 month data tend to over-predict the degradation while the others are more forgiving or under-predict the vitamin degradation. For the purposes of staying ahead of the risk of malnutrition for the crew, this should be taken into consideration.</p>
Task Progress:	

	<p>Freeze drying provided interesting results. The improvement to thiamine’s degradation after drying is not universal and does not abide by an obvious temperature dependency, although it does appear that the lower temperature storage has a stronger or nearly neutral impact on vitamin preservation. Interestingly, the freeze-dried versions of the vitamin B1 foods demonstrated lower vitamin B1 stability at the highest temperature tested compared to wet versions. This was also showcased in vitamin C foods too. With vitamin C, predictive curves fitted 4 and 37°C storage temperatures the best for all the foods with a few good fits at 20°C. Theoretically, the model is most reliable with multiple pair endpoints to generate multiple kTref and c values. Collectively, the average will give a better grasp of the kTref and c kinetic parameters compared to one kTref and c value. To improve model fit at room temperature, we believe collecting endpoints only at 20°C and changing timepoints could significantly improve the fit, although predictions for non-room temperature storage conditions would be less reliable. This is also applicable for retort thermoprocessing and vitamin B1.</p> <p>Overall, much more vitamin retention data has been gathered and processed into separate, time-distinct, predictive models for use by NASA. The degradation parameters used to produce each model have been revealed for all foods. Based on raw content reports, the nutritional content can be assessed for thermoprocessed vitamin B1 foods for up to 18 months and for up to 21 months for vitamin C foods. Freeze-dried vitamin B1 foods can be assessed at 15 months and vitamin C foods can be assessed at 16 months.</p> <p>In conclusion, we plan to continue our analyses to find the set of data for building the most effective and accurate model for making future predictions or interpolating to predict vitamin content if storage temperature is changed. At this point, analysis has been optimized and streamlined for all of our foods, wet or freeze dried. We also have a few publications pending on isothermal degradation and modelling of vitamin B1 and C. The literature review for vitamin C has been officially published in the Critical Reviews in Food Science and Nutrition called “Modeling the degradation kinetics of ascorbic acid.” [See 2017 Task Book Bibliography or Cumulative Bibliography link]</p>
Bibliography Type:	Description: (Last Updated: 09/02/2019)
Articles in Peer-reviewed Journals	McClements DJ, Saliva-Trujillo L, Zhang R, Zhang Z, Zou L, Yao M, Xiao H. "Boosting the bioavailability of hydrophobic nutrients, vitamins, and nutraceuticals in natural products using excipient emulsions." Food Res Int. 2016 Oct;88(Pt A):140-52. Epub 2015 Nov 19. https://doi.org/10.1016/j.foodres.2015.11.017 ; Review. PubMed PMID: 28847393 , Oct-2016