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Project Title:	Food Fortification Stability Study		
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Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Space Human Factors Engineering		
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COI Name (Institution):	Douglas, Grace Ph.D. (NASA Johnson Space Center) Cooper, Maya M.S. (Lockheed Martin/NASA Johnson Space Center)		
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Task Description:	NASA has established the goal of traveling beyond low-Earth orbit and extending manned exploration to Mars. The length of proposed Mars missions and the lack of resupply missions increases the importance of nutritional content in the food system, which will need a five year shelf life. The purpose of this research is to assess the stability of vitamin supplementation in traditionally processed spaceflight foods. It is expected that commercially available fortification nutrients will remain stable through a long duration exploration mission at sufficient levels if compatible formulation, processing, and storage temperatures are achieved. Five vitamins (vitamin E, vitamin K, pantothenic acid, folic acid, and thiamin) were blended into a vitamin premix (DSM, Freeport, TX) such that the vitamin concentration per serving equaled 25% of the recommended daily intake after two years of ambient storage. Four freeze-dried foods (Scrambled Eggs, Italian Vegetables, Potatoes Au Gratin,		

Noodles and Chicken) and four thermostabilized foods (Curry Sauce with Vegetables, Chicken Noodle Soup, Grilled Pork Chop, Rice with Butter) were produced, with and without the vitamin premix, to assess the impact of the added fortification on color and taste and to determine the stability of supplemental vitamins in spaceflight foods.

Rationale for HRP Directed Research: This research is directed because it contains highly constrained research, which requires focused and constrained data gathering and analysis that is more appropriately obtained through a non-competitive proposal.

Research Impact/Earth Benefits: The Food Fortification study will bring vitamin stability knowledge of supplements in food to the open access environment, which will help smaller food manufacturers improve the nutrition of their foods without assuming the prohibitive cost of shelf life research. The data should promote wise fortification of foods. Large-scale companies treat vitamin stability data as proprietary knowledge.

Vitamin E
Year one stability data shows that vitamin E is relatively stable in fortified samples of spaceflight food. In all cases, vitamin E content remained above 25% of the recommended daily intake, regardless of storage temperature and product type. However, vitamin E content in fortified Rice with Butter fell slightly below the 85% desired retention marker after one year of storage at 4°C and 35°C. While this was not a notable decrease, it is important to monitor vitamin stability over the next year of storage and determine the extent that this instability may be an issue over a longer shelf life.

Grilled Pork Chop showed a drastic spike in vitamin E content following one year of storage at 4°C, which may have been caused by uneven vitamin dispersal resulting in over-fortification of the pouches used for year one nutrient analysis. Similar increases have been observed in tomato products following exposure to mild heat treatment. However, the exact cause of this phenomenon is unknown (Rickman 2007). Two year storage data will indicate whether the spike was an issue of vitamin dispersal or an anomaly. Despite this occurrence, it is evident that vitamin E is relatively stable in all test products.

Vitamin K

Year one stability data is consistent with previous work, which demonstrates that vitamin K is resistant to heat and likewise retained during the cooking process (Lešková 2006). In most cases, vitamin K concentration in fortified space foods remained above 25% of the recommended daily intake after one year of storage. The only exceptions were Noodles with Chicken and Scrambled Eggs, whose vitamin K contents fell below 25% of the recommended daily intake after one year of storage at 21°C and 35°C, respectively. Furthermore, vitamin K content in both Noodles with Chicken and Potatoes Au Gratin fell below 85% of the initial fortification level after one year of storage at all temperatures. While the compound appears to be unstable in these products, the sporadic nature of the data makes it difficult to draw conclusions about overall vitamin K stability over time. In the case of Scrambled Eggs, vitamin K levels appear to increase by about 30% after one year of storage at both 4°C and 21°C. Likewise, vitamin K levels in Curry Sauce with Vegetables, Grilled Pork Chop, and Italian Vegetables all appear to increase following one year of storage at 35°C. Such inconsistencies are likely a result of high pouch-to-pouch variability, which is caused by inadequate mixing during sample preparation, and the lack of replicate analysis due to cost constraints. Year two data may reveal any trends in overall vitamin K stability.

Thiamin

Thiamin is a relatively unstable compound that is sensitive to a number of factors, including pH, water activity and temperature (Ryan-Stoneham 1997; Kimura 1990; Arabshahi 1988). Of these factors, temperature appears to have the greatest impact on overall stability, with degradation increasing proportional to changes in temperature (Lee 1988; Mulley 1975; Feliciotti 1957). This temperature-dependent relationship is exhibited in year one stability data, where thiamin degradation is most apparent in thermostabilized samples stored at 35°C. In all cases, thiamin content in fortified thermostabilized foods fell below 25% of the recommended daily intake, suggesting that the continued degradation of thiamin is related to the processing method. This is especially true for Chicken Noodle Soup, whose thiamin concentration fell below 85% of the initial concentration, following storage at all temperatures. Conversely, thiamin levels in freeze-dried foods remained relatively stable during storage at all temperatures, including 35°C. The stability noted in freeze-dried samples indicates a sharp temperature stability cutoff since previous work shows that the compound is readily degraded in dehydrated foods stored at temperatures above 37°C (Dennison 1977). If thiamin stability is maintained in freeze-dried foods after two years of storage then fortification of freeze-dried foods may be a solution for ensuring consistent thiamin delivery in the diet.

Interestingly, Grilled Pork Chop experienced the highest degree of thiamin degradation (120% over one year of storage at 35°C), despite receiving initial vitamin dosages that were 2.7 to 3.3 times greater than the end-of-shelf life goal concentration. Such results are contrary to previous studies, which indicate that doubling initial thiamin concentration actually improves vitamin retention over time (Lee 1988). In this study, it is plausible that the fortificant wasn’t evenly distributed throughout the product, resulting in a high degree of pouch-to-pouch variability. At this point, additional replicate analysis is cost prohibitive, therefore it is difficult to draw conclusions about the stability of thiamin in these samples. Year two data should reveal the extent to which this is a problem.

Folic Acid

Folic acid concentration in most products remained above 25% of the recommended daily intake after one year of storage. Rice with Butter was the only exception, with folic acid content decreasing by 98% -126% after six months and one year of storage at 35°C, respectively. Folic acid content in this product fell below 85% of the initial vitamin content after one year of storage at all temperatures. While the stability of folic acid has not been evaluated previously in thermostabilized rice specifically, it is understood that the method of fortification plays a key role in overall vitamin retention over time (Kam 2012; Sherstha, 2003; Fieger 1945). Kam et al. noted that fortification of brown rice via parboiling resulted in 90% retention of the compound after steaming and cooking (Kam 2012). Conversely, it has been shown that fortification via edible coatings was not effective in preventing folic acid leeching during cooking (Sherstha 2003). In this case, it may prove beneficial to change the method of fortification so that the vitamin is better incorporated into the food matrix.

Pantothenic Acid

Task Progress:

Pantothenic acid levels in most products remained above 25% of the recommended daily intake. Similar results showing that the compound is stable in a wide array of foods have been previously described (Lešková 2006). However, pantothenic acid levels in Curry Sauce with Vegetables decreased by 82% and 120% after six months and one year of storage at 35°C, respectively. This decline can be attributed to a combination of factors, including sub-optimal pH, processing temperature, and processing method (Hamm 1978). However, previous studies only examine the relationship between temperature and pH. The compound appears to be most stable at pHs between 5 and 7 (Kilcast 2011; Hamm 1978). The blended pH of Curry Sauce with Vegetables is approximately 4.35, therefore it is likely that the compound was more susceptible to external influences, such as processing temperature or possibly unfavorable ingredient interactions. Unfortunately, studies to date have only been conducted with model systems, therefore no data is available to suggest whether ingredient interactions may have an effect on stability of multi-component products, such as Curry Sauce with Vegetables.

Sensory Evaluation

The organoleptic quality of fortified space foods was maintained after one year of storage at 4°C and 21°C. In most cases, products stored at these temperatures received overall acceptability ratings of 6.0 or higher on a 9pt hedonic scale. However, samples stored at 35°C only maintained product quality through the first six months of storage. Four products in particular: Italian Vegetables, Scrambled Eggs, Chicken Noodle Soup and Curry Vegetables received unsatisfactory scores (less than 6.0 on a 9 pt. hedonic scale), following one year of storage at 35°C. Of these products, only Scrambled Eggs and Italian Vegetables received scores that were notably lower than their initial ratings, indicating that product quality degradation had occurred. These scores indicate that even brief periods of storage temperature increases during a long duration mission could have notable effects on food acceptability.

Studies evaluating the shelf-life of similar products also noted that the rate of quality loss was temperature-dependent (Ali 2001; Rosenfelda 1999; Sharp 1986). In most cases, products stored at high temperatures develop undesirable flavors much faster than products stored at low temperatures. Such deterioration is likely a result of lipid oxidation and various chemical reactions, which occur at a faster rate during high temperature storage (Steele 2004; Huis 1996). Therefore, it is expected that products stored at low temperatures would maintain product quality for longer periods of time.

Color Analysis

After six months of 35°C storage the only products with notable color differences were Noodles with Chicken, the chicken component of Chicken Noodle Soup and the gravy component of Grilled Pork Chop, which had delta E94 values of 2.5, 2.3, and 2.2, respectively. Color differences between control and fortified foods were far more apparent after one year of storage. This is especially true for the carrot and noodle components of Chicken Noodle Soup, whose delta E94 values between control and fortified samples greatly exceed the threshold of visible detection when stored at 4°C, indicating that fortified samples were most stable under low-temperature storage. There were also measurable color differences between the remaining test products, however these values were not above the threshold of visual detection.

The color stability in the fortified samples compared to the control samples are likely a result of the antioxidant activity of added vitamin E, which is known to slow chemical reactions that lead to color change. The compound acts by inhibiting the propagation of free radicals that are formed during lipid oxidation, making it an ideal preservative for high-fat foods. Therefore, the compound has been used extensively in the food industry to extend the in-store shelf life of meat and poultry products (Jensen 1998; Faustman 1989). Likewise, vitamin E may be contributing to slow the development of off-colors in stored space flight foods (especially meat-containing products), however it does not completely prevent color change over time.

At six months, the only products with notable color differences were Grilled Pork Chop and the carrot and noodle components of Chicken Noodle Soup. However, the inhibitory effects of fortification were only observed in the meat component of Grilled Pork Chop and the chicken component of Chicken Noodle Soup. The delta E94 values for these meat items were less than half of their unfortified equivalents. The spike observed in fortified Scrambled Eggs is likely a result of uneven cooking, in which certain samples appear darker than others. Despite this anomaly, it is apparent that all products experienced notable color change over time.

The one year storage data demonstrates that the extent of color degradation varies greatly by storage temperature and product composition. At 4°C, most products, with the exception of Potatoes Au Gratin, Scrambled Eggs and Noodles with Chicken experienced visually notable color change over time. However, delta E94 values for all fortified products were notably lower than the unfortified versions, indicating that vitamin E greatly reduced the rate of color degradation in stored samples. Products stored at 21°C followed similar patterns of degradation. The delta E94 values for the unfortified samples exceeded that of the fortified version for all items except Rice with Butter, Noodles with Chicken and the gravy component of Grilled Pork Chop. At 35°C, delta E94 values for most products exceeded the threshold of visible detection, however the inhibitory effects of fortification were far less apparent. This is especially true for Chicken Noodle Soup, Potatoes Au Gratin, Rice with Butter, and Noodles with Chicken, whose fortified delta E94 values were equal to or greater than their unfortified equivalents. In this case, it is possible that high-temperature storage sped the rate of color degradation, such that the inhibitory effects of fortification became obsolete. Nonetheless, it is apparent that all items experienced measurable color degradation over time.

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