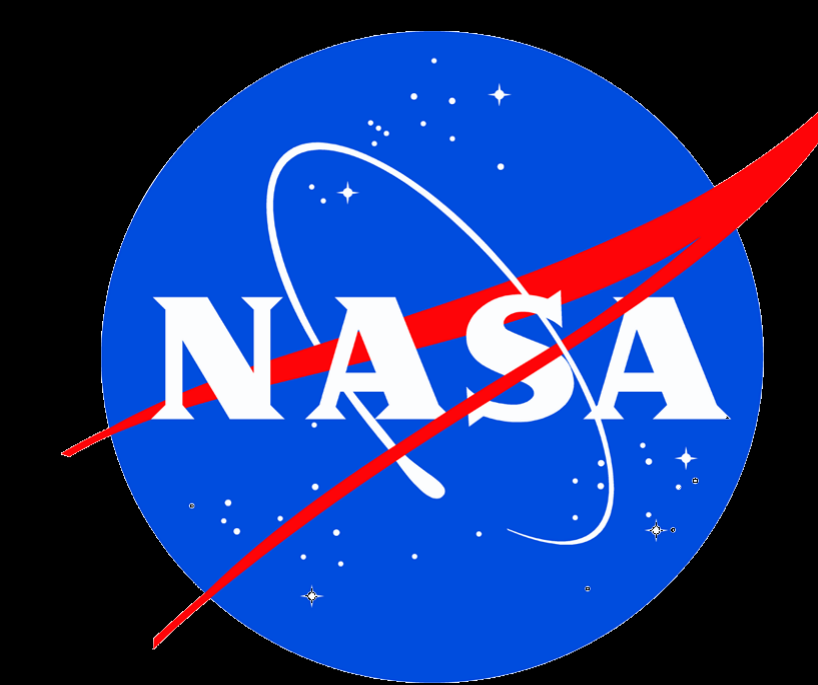


Food Fortification Stability Study

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OBJECTIVES

This study aims to assess the stability of vitamin content, sensory acceptability and color variation in fortified spaceflight foods over a period of 2 years. Findings will identify optimal formulation, processing, and storage conditions to maintain stability and acceptability of commercially available fortification nutrients. Changes in food quality are being monitored to indicate whether fortification affects quality over time (compared to the unfortified control), thus indicating their potential for use on long-duration missions.

METHODS

Selection of Vitamins

Previous Advanced Food Technology (AFT) research has identified five compounds (phyloquinones [vitamin K], thiamin [vitamin B1], folic acid [vitamin B9], pantothenic acid [vitamin B5] and tocopherols [vitamin E]) as candidates for the fortification blend. These compounds show significant degradation trends in the spaceflight food system and may not be adequately available on long-duration missions. Vitamin selection was based on the following criteria:

- Is vitamin concentration in the current International Space Station (ISS) diet adequate to meet Recommended Daily Intake (RDI) after 2 years of ambient storage?
- Has a countermeasure other than food fortification already proven stable and readily available?
- Are both water- and fat-soluble vitamins represented in the vitamin selection of the study?

Preparation of Vitamin Premixes

The above vitamins were blended into a premix (DSM, Freeport, TX), such that the final concentration per serving would be expected to equal 25% of the RDI after 2 years of ambient storage. Fortification nutrient stability will be considered acceptable if at least 85% of the original dose remained after 2 years of ambient storage.

NOTE: All premixes were developed with consideration for thermal process, water activity (aw) and packaging requirements. The result was separate premixes for thermostabilized and freeze-dried foods.

Sample Preparation

Eight food products (table 1) were selected on the basis of nutritional content, processing method (freeze dried vs. retorted), food matrix and formulation, and ease of fortification.

Table 1. Fortified Space Foods

Freeze Dried Foods	Thermostabilized Foods
Potatoes Au Gratin	Curry Sauce with Vegetables
Scrambled Eggs	Chicken Noodle Soup
Italian Vegetables	Grilled Pork Chop
Noodles and Chicken	Rice with Butter

All samples were processed according to standard ISS production specifications; each batch was sized to deliver about 180 servings of product. Two-thirds of each batch was fortified with the vitamin premix and the remaining product served as the control. Packages of fortified and control foods were placed into chambers at 4°C, 21°C, and 35°C for sensory, color, and nutritional evaluation through 2 years of storage.

NOTE: In an effort to preserve quality, all freeze-dried foods were placed into nitrogen-flushed metal cans (with O₂ scavengers), immediately after production (according to spaceflight specification) until they could be packaged into individual servings.

Evaluation

Sensory Evaluation- Untrained panelists (n ≥ 25) evaluated samples for overall acceptability, appearance, aroma, flavor, texture, and color, using a 9-point hedonic scale after 6 months (35°C), and 1 year (4°C and 21°C) of storage. Samples scoring 6.0 or higher are considered acceptable (according to current space food acceptability guidelines).

Color Measurements- Color analysis was conducted at each time point (in triplicate), using the Hunter D25LT Colorimeter (HunterLab, Reston, VA) after 6 months (35°C), and 1 year (4°C and 21°C) of storage. Color differences were reported as ΔE values (difference between initial and 6-month L-a-b score). To optimize color evaluation, heterogeneous samples were divided into individual components and analyzed separately. Color evaluation was performed as follows:

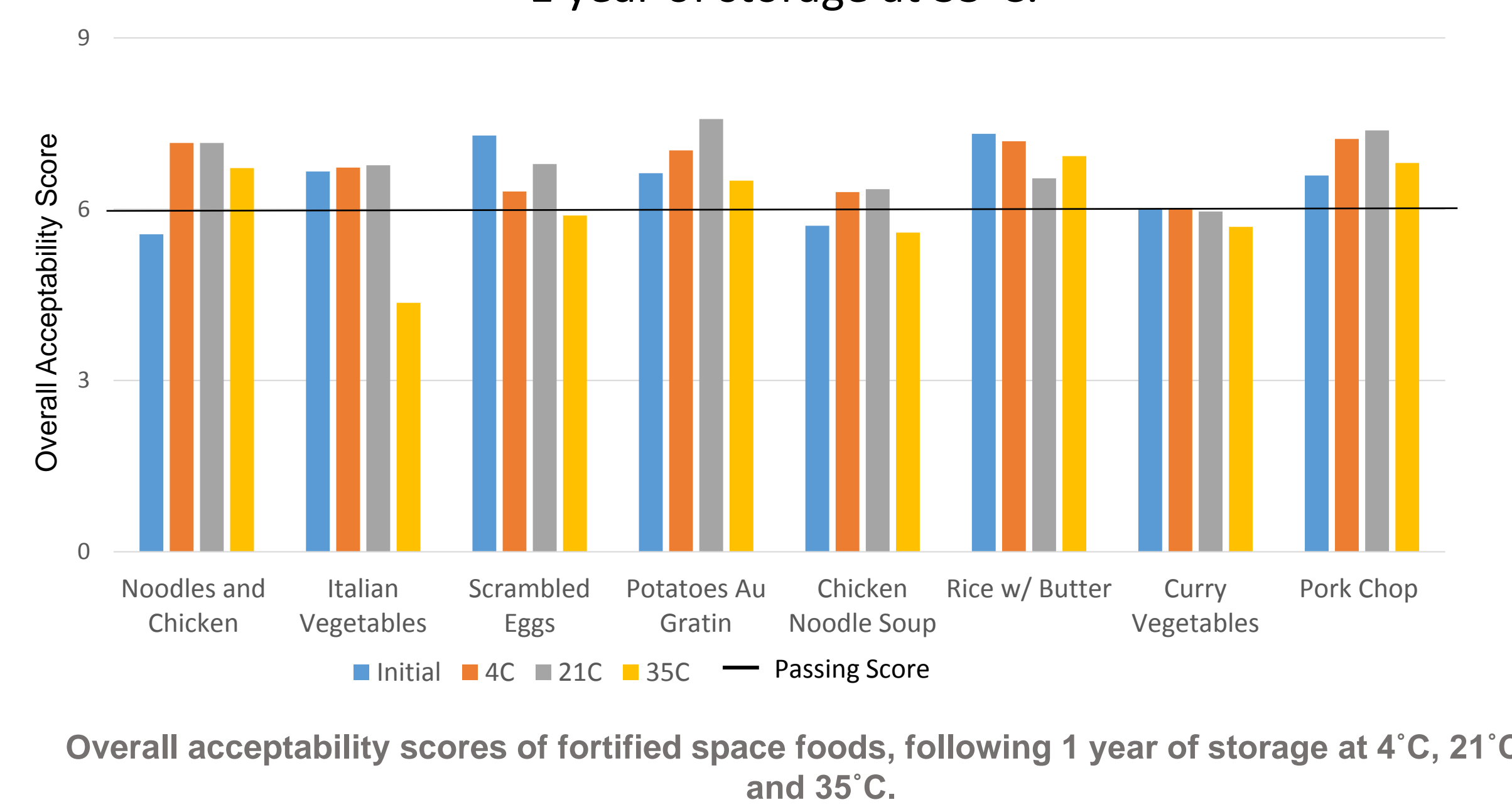
- Grilled Pork Chop was separated into gravy and chop.
- Chicken Noodle Soup was divided into chicken, noodles, carrots and sauce.
- Curry Sauce with Vegetables was blended into a puree.
- Rice with Butter was tested as-is.
- All freeze-dried products were ground into coarse crumbs.
- Italian Vegetables was excluded from color analysis, because the freeze-dried pouches were too small for component separation and individual components differ greatly in color, making it difficult to produce meaningful data.

Chemical Analysis - Three packages of fortified and control foods were sent to Covance Laboratories (Madison, WI), after 6 months (35°C) and 1 year (4°C and 21°C), and analyzed for folic acid, pantothenic acid, thiamin, vitamin E (natural) and vitamin K1 content, according to AOAC official methods (Official Methods of Analysis of AOAC International ed.).

RESULTS

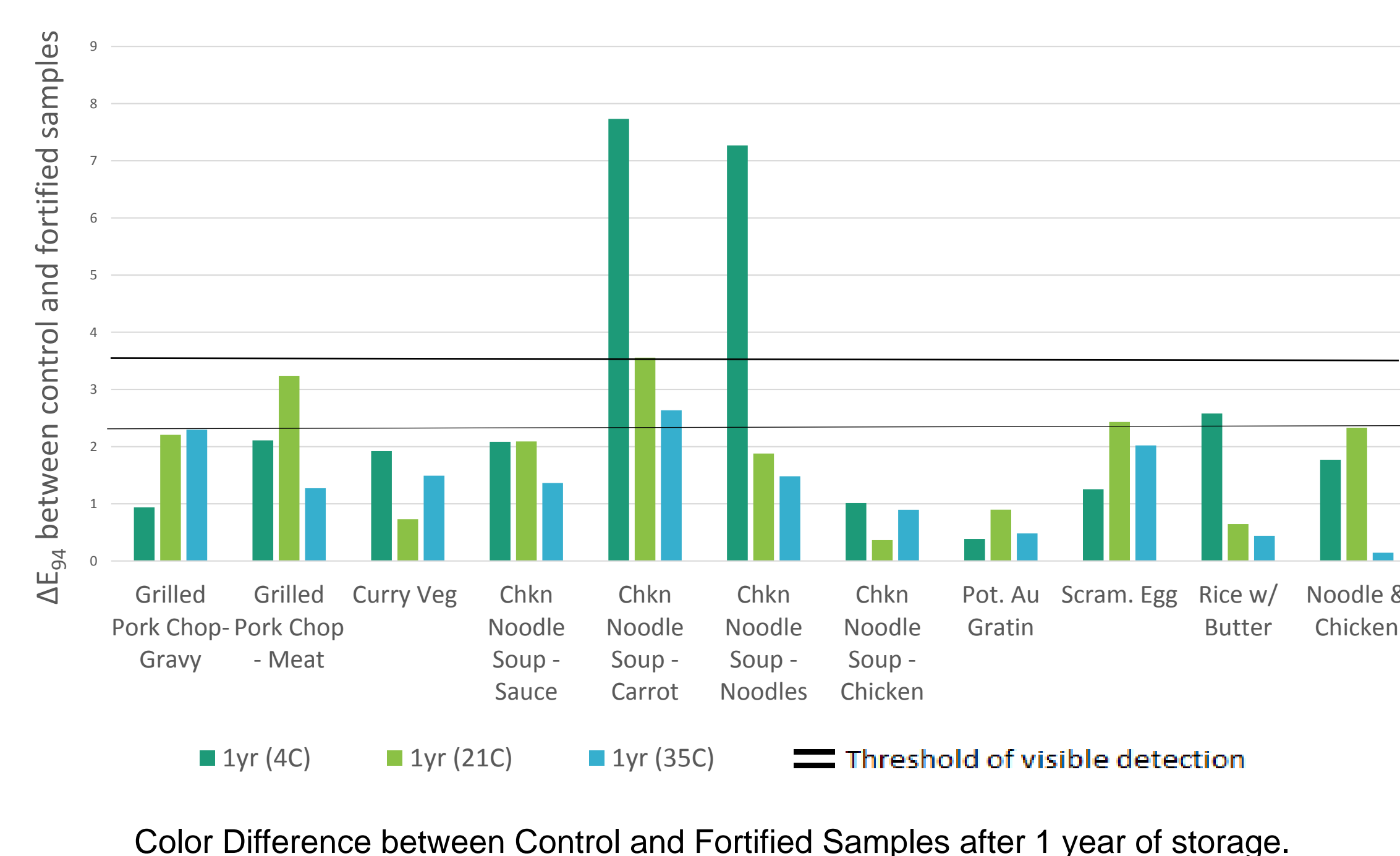
Sensory Analysis

The organoleptic quality of fortified space foods was maintained after 1 year of storage at 4°C and 21°C. Italian Vegetables, Scrambled Eggs, Chicken Noodle Soup and Curry Vegetables received unsatisfactory scores following 1 year of storage at 35°C.

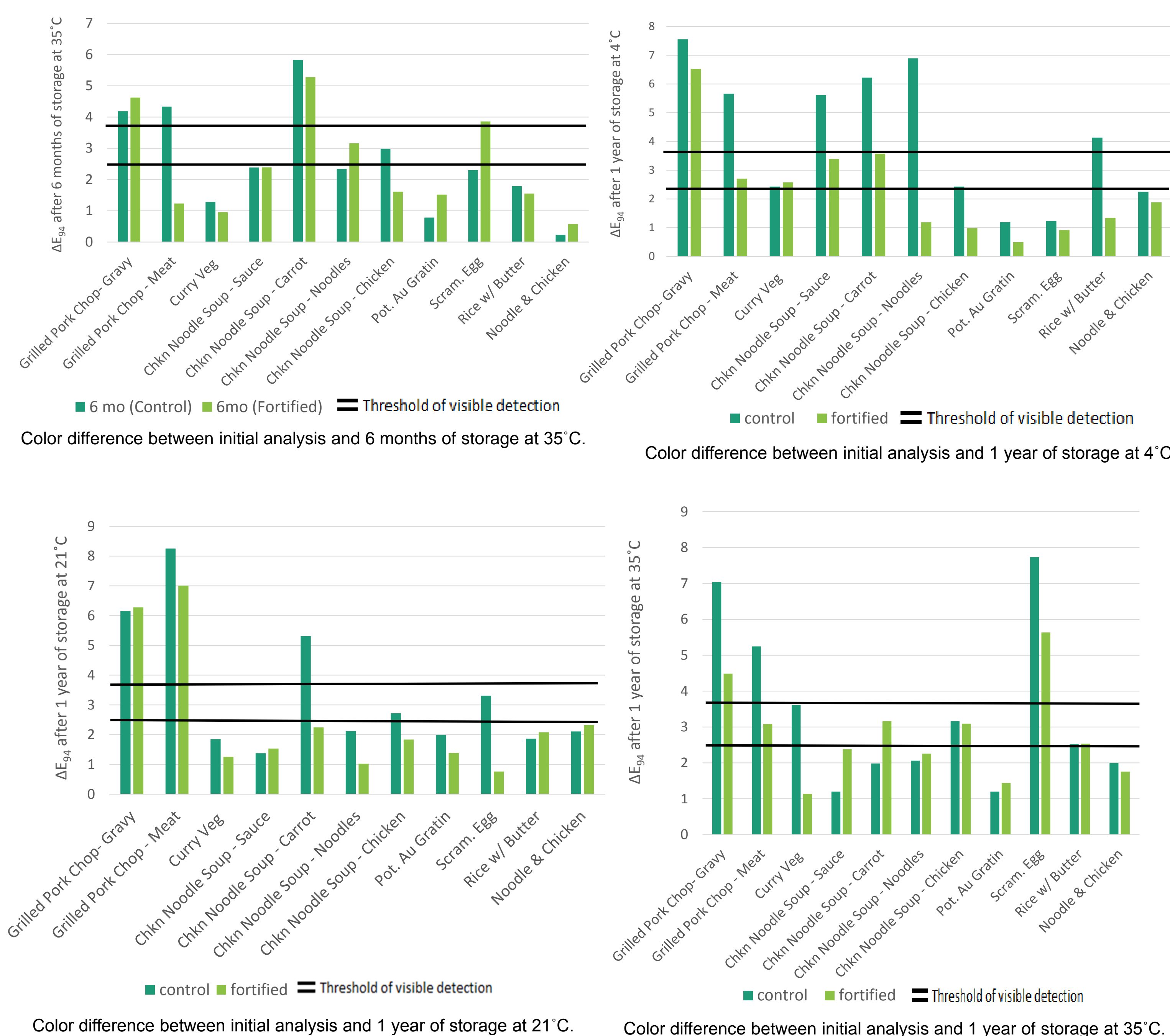


Color Analysis

There were notable color differences between control and fortified samples of Chicken Noodle Soup-carrot and Chicken Noodle Soup-noodle after 1 year of storage at 4°C. There were also visually detectable color differences between control and fortified samples of Grilled Pork Chop-meat and Chicken Noodle Soup-carrot after 1 year of storage at 21°C.

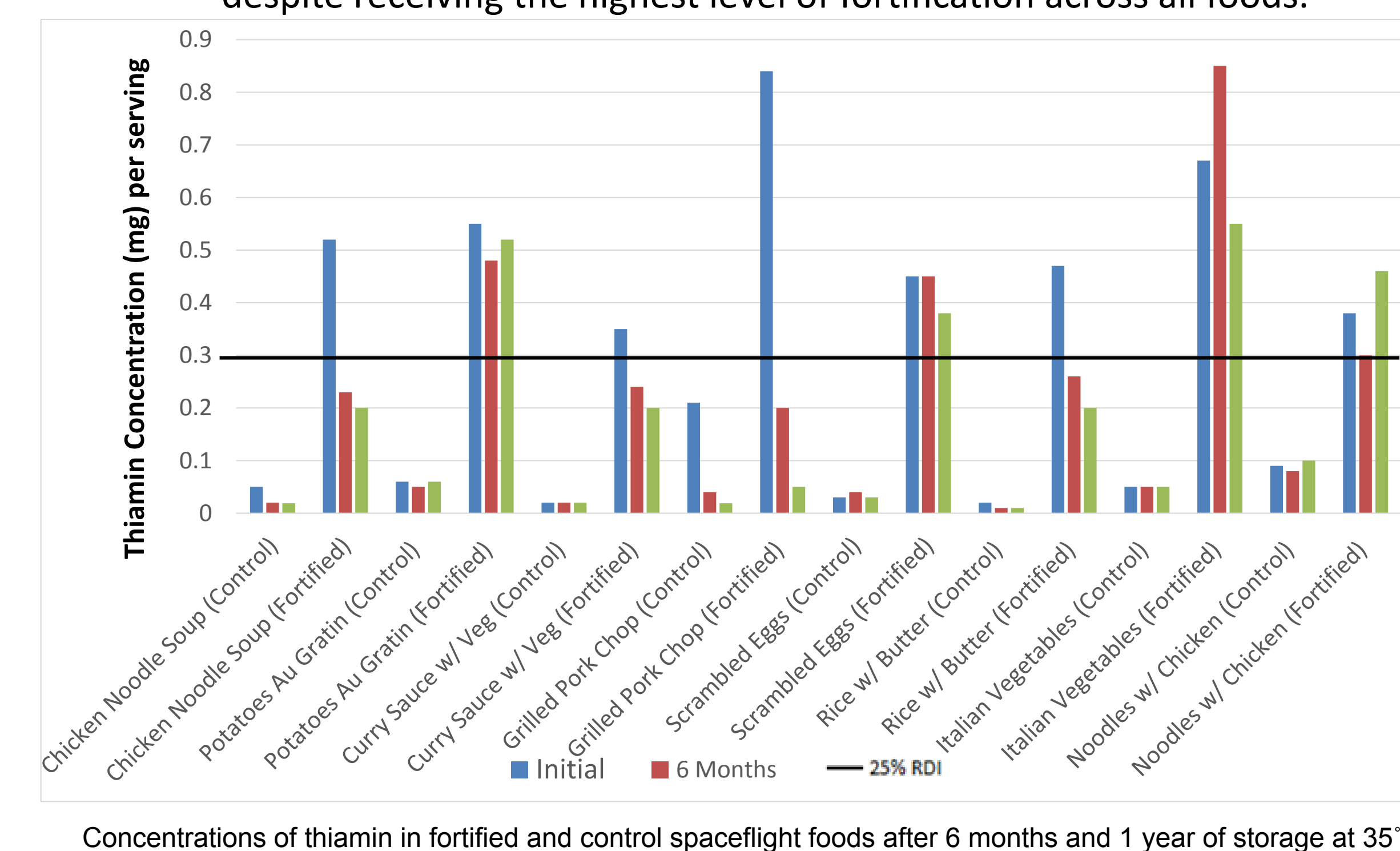


ΔE values for most fortified products were significantly lower than the unfortified versions during low-temperature storage. At 35°C, ΔE values for most products exceeded the threshold of visible detection, regardless of fortification.



Nutrient Analysis

The vitamin premix is relatively stable in most foods after 1 year of storage. The only exception is thiamin, which appears to be unstable in thermostabilized foods, during elevated temperature storage. Grilled Pork Chop had the greatest loss after 6 months and 1 year, despite receiving the highest level of fortification across all foods.



CONCLUSIONS

- Vitamin fortification reduces the rate of color degradation in stored space foods; however, this activity is negated by high-temperature storage.
- Vitamin fortification does not have a negative impact on sensory properties of space foods, and 1-year data indicates that low-temperature storage (4 and 21°C) may maintain higher acceptability.
- Vitamin fortification is a feasible option for delivering at least 25% of the RDI of vitamin E, vitamin K, folic acid and pantothenic acid; thermostabilization is detrimental to thiamin stability.
- High-temperature storage seems to have a negative impact on all test criteria, so use of refrigeration may prove beneficial during long-duration missions.

FUTURE WORK

Samples that are stored at 4°C and 21°C will be evaluated after 2 years for sensory acceptability, vitamin content and color degradation. Final results will be used to determine the overall stability and acceptability of commercially available fortificants.