A methodical study of overall food system design for space shuttle flight - A Food Safety & Nutritional Requirement

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Abstract. Purpose: The concept of eating aboard, to consume in the machinery-filled weightless environments in a spacecraft is different. It can be affected by biological, operational, and engineering factors in a spacecraft. These factors involve the effect of the food and the aesthetic structure of the food's container. The paper talks about Food in space. Requirements of astronauts who go for space exploration, in terms of their nutritional requirements and allowances.

Background: The astronauts in spacecraft must have good food and nutrition to keep their psychology and physiology in good shape. There are various alternatives for feeding astronauts for short term and long term missions to celestial bodies. It covers various aspects like nutritional values and RDA, Food Safety protocols. To understand why space food is different from regular food on earth and what can be done to keep the taste as close to natural as possible and the human experience of eating in space needs to be explored.

Methodology & objectives: Our study will focus on the food which is consumed on the space ship, its origin, advances, and requirements of nourishment through food onboard a space ship, its effect, and the long term implications of eating processed food. This paper will try to address the history and development of space food over the years with an emphasis on the functional and nutritional aspects of food.

Conclusions/discussions: Through this paper, we aim to explore the future of space travel that complies with nutrition requirements (Enrico, 2016) and at the same time strengthens efforts to consider food for health and wellness (Nestle et al. 2009) but also as a reason of delight. It is important to think beyond the functional purpose of food in the context of space exploration. We intend to research in human-food interaction design and build on insights from food science and multisensory research, of components in the restricted space environment that can be crucial for a pleasant food experience.

Keywords: Space Food, Nutrition, Safety, Environment, Astronauts

1 Introduction

Space food is another dimension designed for consumption in space. The nutritional intake is a deterrent and prioritizes concern on the health and performance of astronauts engaged in and also after the space flight. There have been studies in the nutritional aspect addressing the bioavailability and nutritional requirement amendments for the space crew members and there is limited information available on the level of stability of nutrients on the shelf life of the food system. The most common means of transporting the service of space food is in the form of the processed and pre-packaged food system. The allied stakeholders in this delivery till late were the logistics and resource availability which restricted the use of fresh and refrigerated food systems. Despite good development in the pharmaceuticals, the supplements cannot replicate the numerous bioactive compounds and the synergies that are provided through whole foods and a balanced diet. When we talk of a remote environment, it demands a system that can deliver high quality, safe and hygienic food provisions inadequate balance that would require minimum storage facilities and storage period ranging from 1-5 years. The food when consumed should not be insipid, good in shape, color, texture reasonably of the best quality also in providing required macronutrients, vitamins, and minerals.

The mode of the current International Space Station (ISS) food system comprises of processed foods that are vacuum-packaged in high- barrier laminates with an aluminum foil layer that is not only safe

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microbiologically but also compatible with microgravity as is the resultant environment. The food safety norms are conceptualized by the cook-freeze food system, irradiation, or retort thermostabilization processing. This enables chemical and structural changes that help to modify the food quality and stability. The production cycle in its storage impacts the vitamins but the data available doesn't reiterate packaging and shelf-life parameters. The evaluation of the spaceflight food system's nutritional stability, indicate that vitamins B1, B9, K, and C have shown signs of degradation. The concept of eating aboard, in a micro gravitational environment inside a spacecraft for astronauts is very difficult. It can be affected by either or biological, operational, and engineering factors in a spacecraft further affecting the aesthetic structure of the food's container.

2 Background

The astronauts in spacecraft must have good food and nutrition to keep their psychology and physiology in good shape. There are various alternatives for feeding astronauts for short term and long term missions to celestial bodies. It covers various aspects like nutritional values and RDA, Food Safety protocols. To understand why space food is different from regular food on earth and what can be done to keep the taste as close to natural as possible and limited studies on astronaut experience of eating in space

Planning and dispensing a well-balanced meal for the astronaut team is a complex issue. This compilation tries to address the degree of that complexity, nutritional intake from the mechanized food system. The foods undergo fortification or supplementation as a nutritional countermeasure, the supplements in the form of capsules may degrade and are subject to major approval to consumption. Studies have been conducted on the stability of foods processed with microwave-assisted thermal stabilization (MATS) in contrast to current thermal processing methods, and extended to frozen or refrigerated storage for all space foods. It has been concluded as a shorter thermal exposure in MATS processing and the slowed kinetic rates of chemical degradation at reduced temperatures are expected to improve vitamin stability and increase shelf life. Convincible proof has been documented regarding the bio regenerative salad crop system being grown in-ground chambers and on the ISS thus illustrating favorable horticulture methods used to enable crops to be grown in spaceflight that could help supplement nutritional needs.

The 1960s witnessed advancement in technology with the mission of sending men into space by NASA. The important element of wellbeing took some more time to be perfected - the food. A lot of research and development has taken place in the development of space food. It has not only increased the number of items on the menu it has also intensified the safety concern in the wellbeing with choices available. It is fortunate to know that these days' astronauts are even getting treated to gourmet meals designed by celebrity chefs. An experience that is way apart from the dining /eating habits, what food does to the health of the astronaut as it is a time-bound excursion and the prelims of the manner of shipment and consumption convenience involved in the interest of the astronaut's wellbeing en process?

The health of the astronauts is dependent on factors that determine the characteristics of space food in terms of being Biological, Engineering, and Operational. The biological factors in food design make the food palatable, safe, nutritious. It must also be easy to digest and should not result in any kind of gastroenterological or hygiene problems. The engineering factors help to make the food dehydrated to make it lighter, compact, durable, lightweight as the expedition is of longer duration, under restricted temperature, pressure, acceleration, and vibration of flight. The operational factors involve both the food preparation and its packaging, which can be easily prepared, with a longer shelf life and food must be easy to both prepare and dispose of to save time. While there are no provisions to refrigerate the food and most of the food is dehydrated or from the cook-freeze. No fresh fruits or vegetables to savor in their tenure of a few weeks or months. One of the major differences between space food and regular food is in the packaging and design. Space food needs to be confined in the low-gravity (microgravity) environment. Crumbs can become deadly in low gravity if get lodged in shuttle vents or nose or mouth and pose a choking or breathing hazard. Drinks like tea, coffee, orange juice, apple cider can pour and float so are packaged as powders. Astronauts add water to rehydrate to consume them. Tortillas are used instead of bread. Condiments like ketchup, mustard, and mayonnaise are provided in their standard forms, but salt and pepper are provided only in liquid form. Astronauts tend to eat 70% less food than people on Earth. Once done with eating, throw their packages away in a trash compactor inside the space shuttle.

3 Objectives

- To study advancement in space food systems
- To understand nutritional requirements through food onboard a space ship
- To explore the future of space foods

3.1 Space food systems

The Space Food Systems evolved as U.S. space programs:

- 1961–1963 - The Mercury program
- Space food was packaged in bite-sized cubes, freeze-dried powders, and semi-liquid foods (such as ham salad) stuffed into aluminum tubes.
- 1965–1966 - The Gemini program
- In addition to the mercury program, bite-sized cubes were coated with plain gelatine so that the crumbs could be reduced thereby prevent clogging the air-handling system. Freeze-dried foods were stored in plastic containers to make rehydrating easier.
- 1968–1972 - The Apollo program
- This program was the first to have hot water for rehydrating foods and also improve the taste and quality. This program saw the use of the spoon bowl, a utensil that eliminated having to consume the food into the mouth directly from the package.
- 1973–1974 - The Skylab program
- As years have gone by, the research and development helped improve the quality, taste, and variety of foods. This program saw the use of refrigerators and freezers to store fresh foods (72 different food items).
- 1981 - The Shuttle program,
- This program saw the inclusion of grocery stores. Three- meal-per-day menus that were planned by dieticians to contain a balanced supply of the nutrients needed throughout the tenure. Freeze-dried foods were re-hydrated using water that is generated by the Shuttle's fuel cells. Foods could be heated in a convection oven in the Shuttle galley.

Nutrition has played a critical role in the explorations about their extent, storage, and pro-crew facilities. Long-duration spaceflight needs to meet the nutrient requirements for the wellbeing of the astronauts in the restricted environment. It has been derived that due to microgravity, astronauts lose calcium, nitrogen, and phosphorus. The loss is to be mitigated with sustainable characteristics like adequate nutrient supply, lightweight, compact, easily digestible, palatable, physiologically appropriate, well packed, well stored, easy to clean-up, high acceptability with minimum preparation, higher shelf life with no compromise on the quality concern.

There are certain codes for the foods that are sent into space, namely:

- (B) - Beverages - Rehydratable drinks.
- (FF) - Fresh Foods - Foods that spoil quickly - eaten within the first two days of flight
- (I) Irradiated (I) Meat - Beef steak sterilized with ionizing radiation
- (IM) Intermediate Moisture (IM) - Foods with some moisture
- (NF)Natural Form (NF) - Mostly unprocessed foods that can be had ready - nuts, cookies, granola bars
- (R) Rehydratable (R) Foods – Dehydrated foods that can be rehydrated with hot water to be consumed.
- (T) Thermo-stabilized (T) - Foods processed with heat to destroy micro-organisms and enzymes that may cause spoilage.

3.2 Nutritional fitness

According to a study 109 of 203 foods currently available on the ISS standard menu were selected for nutritional investigation based on the method of stabilization and the primary food matrix. The foods were processed and packaged according to the current space- flight specifications and then stored at 21 °C for up to 3 years.

Later sent to the laboratory (Covance, Madison, WI, USA) for composite analysis of 24 vitamins and minerals following the Official Methods of Analysis of AOAC International.9, 10 Samples were similarly sent after 1 year and 3 years of storage in a 21 °C incubator (temperature on ISS). Foods were prepared accordingly to ISS instructions (rehydration) before analysis.

A few observations concluded:

- The data was categorized group-wise and indicated nutritional degradation of the food system qualitatively.
- Astronauts need less iron than they do on Earth to manufacture new red blood cells but astronauts have fewer red blood cells in space. Excessive intake of iron can result in health issues.
- Astronauts also need extra calcium and vitamin D, because of no proper movement, the bones don't get the exercise they need to stay strong in the weightless environment.
- Food allowances were fixed @ 723 grams of food including packaging per astronaut per day.
- With only soft foods can be an unappetizing experience for the Astronauts.

3.3 Packaging space food

There has been advancement in the packaging for various menu options including fruits and vegetables that can be safely stored at room temperature are eaten on space flights.

A few of the characteristics are as below:

- Warm pouches - Savory shrimp cocktail and apples with black current juice available.
- Clear flexible pouches - Irradiated food and natural foods that are cut with scissors.
- Polyethylene dropper bottles - Condiments like salt and pepper are contained in. Salt is dissolved in water, whereas pepper is mixed in oil.
- Vacuum sealed beverage pouches - Freeze-dried drink mixes (coffee or tea) or flavored drinks (lemonade or orange drink)
- Powdered form - Coffee, tea, cream, and /or sugar

Space exploration mission entails keeping the astronauts healthy for judicious research. During Apollo and Skylab missions laminate of polyethylene was used, followed by injection molded dishes with a flexible lid which was used for rehydrated foods. The advancement in food packaging systems is

- Flexible bowl and lid with a septum adapter - Rehydratable food package
- Aluminum or bimetallic cans - Thermos stabilized foods
- Modified atmosphere packaging techniques - Rehydratable and bite-sized foods
- Refrigeration and quick-freezing - preserve food flavor, nutrients and prevent spoilage.
- Nitrogen Flush - each package is flushed three times before the final seal at 21 to 29 inches Hg vacuum.
- Beverage pouches can be filled for drinking water. Special straws are used for drinking liquids.

3.4 Future of space food

Considering the huge impetus to the quality standards and complications of the niche space food, there are few categories of space foods:

- Functional foods- rich in ingredients
- Space agriculture - food is grown in space
- Bugs and Worms
- 3D printed food

Functional foods are rich in ingredients with functional properties. These characteristics can include – more concentration of antioxidants, water, fiber, and low on salt and sodium. Depending on the commodity, freezing and canning processes may enable to preserve nutrient value. The thermal treatment of processed food products can cause loss of water-soluble and oxygen-labile nutrients such as vitamin C and the B vitamins.

Ex:- Tortillas are heat treated and specially packaged in an oxygen-free nitrogen atmosphere to prevent the growth of mold.

A new form of an agri- system termed space agriculture farming within space flight which in turn facilitates the removal of carbon dioxide from the spacecraft and creates life-supporting oxygen. There are a series of tests to ensure the crop is safe and tastes well for consumption.

Studies have been performed to study International Space Station with three sets of test plants for an initial hardware validation test, designated VEG-01. VEG-01A and B featured the crop red romaine lettuce, while VEG-01C tested 'Profusion' zinnia plants for longer duration growth and flowering characteristics.

Results have space agriculture have shown tomatoes are even juicer and sweeter and seeds different in taste. Vegetables like Radish, romaine lettuce, Chinese cabbage, Green Lettuce, a variety of lentils, and Mustard have been successfully grown and harvested.

Worms and bugs have a high concentration of protein. The bugs reproduce fast and enable to convert inedible into edible foods like mulberry leaves and wood waste etc. Ex- beetles, termites

The most recent development is that of 3d printing may be a breakthrough for the future of space food for long duration missions.

Lab-Grown Meat - Israeli food-tech startup Aleph Farms succeeded in the lab growth of meat in space for the first time, with the help of a 3D printer. The process involves extracting cells from a cow through a small biopsy. The cells are then placed in a "broth" of nutrients that simulates the environment inside a cow's body. Here it grows into a thin steak. These taste good but it's meant to mimic the texture and flavor of traditional beef.

Idli - Defence Food Research Laboratory (DFRL) is working on an Indian menu suitable for space, Idli coins with powders of sambar and chutney. The idlis are cooked and dried using infrared radiation at a temperature of 700*c, and then further dried by microwaving space yogurt developed using pulsed electric field technology in which short bursts of electricity are passed through a fluid food the pack as it is designed now has ten such idlis, equivalent of three normal-sized idlis.

4 Conclusion

Through this paper, we tried to explore the future of space travel that complies with nutrition requirements and at the same time strengthen efforts to consider food not only as a means for survival and health but also as a source of enjoyment. It is important to think beyond the functional purpose of food in the context of space exploration. Our intent to research in human-food interaction design and insights from food science and multisensory research, particularly research is based on the literature available from research studies during explorations. The multisensory components analysis could be crucial for an enjoyable food experience.

We could get an insight into the transition when astronauts in space squeezed their meals from toothpaste-like tubes and today they have an array of fruits, vegetables, condiments with liquid salt and pepper.

Considering the huge cost involved, alternatives of planting by the crew to feed themselves are mentioned in this paper. Through the plantation, exercise reduces the effect of psychosocial isolation, confinement, and long separation from family and friends on the space crew. The proposed high-tech 3D food printers will be a great leap in the space food systems. There have been possible solutions in successfully growing seeds on the selected celestial destinations.

5 Implications

This paper can act as a refresher scope to the research and development in space food systems with methods involved in food specifications, food packaging, preservation and storage aids, preliminary and on-board preparation towards nutritional requirements accomplishment. It also draws attention to the impact of spaceflight on human physiology and psychology.

6 Limitations

This paper doesn't address the role of reducing fatigue like muscle atrophy through nutritional adequacy. Limited statistics are available for the fitness of nutrients alteration/ oxidation for long-duration exploration missions in space.

7 Future research

Feeding patterns in Long-duration space explorations to Selected Celestial Bodies – Mars, Venus, etc. An in-depth study on multisensory components of space food fit for consumption in their best form devised. The psychological analysis of astronauts issues, stressors, effects of long-term microgravity and radiation, isolation, gender roles, depression, habitat design.

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