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An overview of the Advancements in Space Food Technology

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INTRODUCTION

Food and nutrition are central to every aspect of health and routine. Throughout history, the adequacy of the food system has been critical to the success of human exploration (Pimentel, 2003; Feeney and Houston, 1998). The field of human nutrition has dramatically advanced over the past hundred years, and we have established the requirements of a safe, nutritious, and suitable food system. As we transition to the era of deep space exploration, it seems frank that we would apply this knowledge to future exploration of food systems. However, resource constraints and shelf-life requirements on space vehicles can conflict with what seems on earth to be basic and crucial food system solutions (e.g., cold storage), exciting food system provisioning as missions become longer and further from Earth. Indian space research organization (ISRO) spends millions of rupees to bring about food innovations in space food while, the American space centre (NASA) has a budget of 22.6 billion dollars to study different innovations in space food and beverages. The very first-time food was eaten in space was by John Glenn, the first American person to eat-in space. Different missions were carried out to enhance the food and beverage innovations techniques. For the first mission, astronauts were provided with two meal packages for the five hours of the mission. High-budget missions are involved in extending the shelf life of the food, beverage and non-alcoholic beverages have gained much importance in the space beverage business.

A surprising amount of alcohol has also travelled on the Russian Mir mission stations, which opened the consumption of alcoholic beverages for the astronauts during the prolonged missions at the space station (Angelo A. Casaburri, 1999). It has shown trending studies about space food and averages include the packaging of the space food and the beverages based upon the textural analysis and their types. Sustainability of a spaceflight food system has many parallels to the challenges of sustainability for Earth-based food systems, and there is potential for solutions that contribute to sustainability in spaceflight to contribute on Earth simultaneously. We are still far from a fully closed food system in spaceflight, as many of the crucial ecosystem components are unavailable. However, to know the extent of this challenge, it is crucial to know the resource challenges linked with spaceflight and how this has driven the current food system solutions.

As nutrition is the process of providing or obtaining the food necessary for health and growth, space nutrition is providing the food necessary for health and growth in space. Nutrition has played a critical role throughout the history of explorations, and space exploration is no exception. Space explorers have always had to face the problem of how to carry enough food for their journeys as adequate storage space has been a problem. Long-duration spaceflight will require the proper nutrient requirements to maintain health and protection against microgravity. Sustaining adequate nutrient intake during space flight is essential not only to meet the nutrient needs of astronauts but also to help counteract the adverse effects of space flight on the human body and to avoid deficiency diseases, i.e., the food needs to be edible throughout the voyage, and it also needs to provide all the nutrients required to avoid diseases. For example, astronauts lose calcium, nitrogen, and phosphorus because of microgravity. Therefore, these lost nutrients need to be gained back through space food which should be nutritious, lightweight, compact, easily digestible, palatable, physiologically appropriate, well packed, quick to serve, easy to clean up, high acceptability with minimum preparation (Angelo A. Casaburri, 1999).

1. Space food and its characteristics

Space food is the variety of food products specially created, designed, and processed for the consumption of astronauts during space missions. Space food exhibit specific characteristics required to study further parameters of space food (Naman, 2017). The general characteristics include: It must be nutritional; it should be easy to digest and palatable; must be low weight; should be appropriately sealed; and quick and easy to clean up.

2. Space food evolution and improvement

As NASA began sending humans to space, there also began searching for food for the astronauts. So far, the development of space food has had to undergo many parameters and analyses to fit into the safe food categories. Different missions were carried out for the innovations of space foods and beverages; the space food did not taste good due to the decreased atmosphere as taste buds' ability was lowered. From 1970 to 1980, culinary options included more than 70 food items at the space station (Sachin Mhalaskar et al 2021). On the first mission, mercury food was available in squeezable tubes. Liquid foods such as juices and soups were introduced at the Gemini mission. For the first time, the packaging material was introduced during the Apollo mission. Skylab mission utensils were introduced before mission food was available in the dehydrated form. Johnson Space Centre invited the astronauts for the taste-testing sessions where their opinions are taken into account for further recommendations of the dishes. NASA has now begun the project on space gardening (Chang 2019).

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3. Types of space food

Scientists and technologists took years to develop the space food and to recognize the practical issues with the meal which were served on the board. The production can be done in various ways of Space Food that is fit to be consumed. The various types of space food in the different forms are discussed in this section. (NASA, 2002; Perchonok et al., 2009)

3.1 Rehydrated foods

Water is removed from rehydrated foods to make them easier to store. The various examples include spiced cereals, toast, etc. Reducing the water reduces the microbial activity in the food products. Rehydratable types of items are available in space foods as well as beverages. Breakfast cereals were also made rehydratable by adding water just before their consumption. Rehydratable food was packaged in a flexible packaging material that was quickly compressible. Food products are rehydrated using hot water before consumption by astronauts (Chang 2019).

3.2 Intermediate moisture foods (IMF)

Intermediate moisture foods (IMF) were produced by restricting the amount of water available for microbial growth. Water is chemically bonded to sugar or salt and accounts for around 15-20 percent. The examples include, dried peaches, pears, and apricots. (IMF) is regarded as one of the oldest foods preserving methods. In this method, the mixing of various ingredients to attain a given water activity (a_w) that allows safe storage for a long time, but at the same time, maintains the eating quality of the food, but this work was only done on an empirical basis.

3.3 Thermostabilised foods

Thermostabilised foods are stable at room temperature and are heat processed. Most of the fruits and fish which are thermostabilised in cans. The other examples include, tomatoes, grilled chicken, and ham. The food is directly consumed using conventional utensils. Plastic cups were used to pack the puddings; while thermostable food products are available commercially in the market in retort pouches. Fruits and vegetables are easily stored using thermostabilised cans. Usually, aluminium foils or bimetallic cans are used as packaging material for the thermostabilised food product (Sachin Mhalaskar et al 2021).

3.4 Irradiated foods

Irradiated foods are those which use ionizing radiation by exposure to x-rays. Irradiated meat had higher organoleptic acceptability compared to thermally processed foods. The meat products are irradiated at 44kGy and Beef steaks are the only example of irradiated space food products (Feeney and Houston 1998). Irradiated food can include any food group, from fruits and vegetables to meat. Despite radiation, these foods do not raise risk of cancer in consumers. World Health Organization and American Medical Association have labelled them as fit to be consumed.

3.5 Fresh and Frozen foods

Fresh foods are available for space flight from the initial days of the mission. Fresh fruits and vegetables are neither processed nor artificially preserved. To ensure food safety, they are sanitized with 200 parts per million (ppm) of chlorine rinse. Vegetables like carrots and celery are packaged in bags. However, since there is no refrigeration on board, these foods are consumed within the first two to three days of the mission. In case of frozen foods, they are quick-frozen to prevent a build-up of large ice crystals and generally include quiches and chicken pot pie.

3.6 Natural form food

Natural food products are readily available for consumption; no further processing is required to make the food product ready. These food products are packed in flexible pouches. These food products are generally granola bars, cookies, nuts and other ready to eat products.

3.7 Condiments

Condiments are generally made available in liquid forms for the astronauts. Pouches are made available for mustard sauce, tomato sauce, and mayonnaise packaging. The salt is dissolved in water and pepper is in the form of oil and is packaged in the polyethylene dropper bottle.

3.8 Tortillas

Tortillas are the types of bread made from wheat and are most liked by the astronauts, but there is a problem with the packaging of the tortillas as it cannot be preserved without refrigeration. Tortillas are a combination of acidity, water activity, and oxygen. There is immediate mold growth if not appropriately preserved. During the dough formation of the tortillas, water activity is reduced to 0.90 and lower acidity is maintained. Microbial growth can be reduced by removing oxygen from the packaging material.

3.9 Freeze-dried foods

Freeze dried foods can be eaten directly without the addition of cold or hot water before consumption. These foods are generally pre-cooked or pre-processed, so no further refrigeration is required. Fruits and vegetables are the only exceptions, as they decay quickly.

4. Missions for space food

The food that NASA's early astronauts had to eat in space is a testament to their fortitude. John Glenn, America's first man to eat anything in the near-weightless environment of earth orbit, found the task of eating relatively easy, but the menu was limited.

5.1 Mercury (1962-1964)

Mercury was the USA's first space program that sent humans to space. It comprised bite-sized cubes, freeze-dried powder, and tubes of semi-liquids. Astronauts found it difficult in rehydrating the freeze-dried foods, and did not like squeezing tubes or collecting crumbs. The flavourof the foods was unchanged, but the texture of food products changed in terms of organoleptic properties. Astronauts disliked the meal on this mission (Feeney and Houston, 1998).

5.2 Gemini (1965-1967)

Gemini's mission was to bring NASA one step closer in going to the moon. In this mission, dehydrated, freeze-dried, bite-sized food with oil coating was done to prevent crumbling. There was improved quality of the food products and their packaging in this mission. This is the mission where shrimp cocktail, chicken and vegetables, butterscotch pudding, and apple sauce were introduced and came up with the meal combinations. With an improved packaging came improved quality and menus in the space missions of the NASA (Feeney and Houston, 1998).

5.3 Apollo (1968-1975)

Apollo mission is where the men landed on the moon. It included thermostabilised and irradiated foods. Hot water, and utensils such as the spoon bowl system and thermo-stabilized pouch were used in this mission. The Apollo mission also introduced thermo-stabilized pouches called wet packs. These wet packs were used to keep the food moist for a long time; before this invention, astronauts rehydrated the food using water (Feeney and Houston, 1998).

5.4 Skylab (1971-1973)

Skylab mission introduced a freezer, refrigerator, warming trays, and a table. Eating a meal on Skylab mission was more like eating at home. Food containers were introduced in this mission. The main aim of this mission was to prove that humans can live in space for a longer time to complete their missions. Skylab missions also included the introduction of 72 different food items. Skylab's mission also included the storage of frozen food products. A simple heating device was also introduced during this mission and heating took place with the mode of conduction at the space station (Feeney and Houston, 1998).

5.5 Apollo-Soyuz docking mission

Apollo spacecraft did not have the freezer that Skylab featured but many of the food advances from Skylab and the earlier Apollo missions were incorporated. Because of the short duration of the flight (nine days), many short life items were added to the foods carried. Fresh bread and cheese were included as part of 80 different foods dined upon by the Apollo, while others were placed in spoon-bowl packages or plastic drinking bags. To make eating more accessible, a food tray was carried on the mission. The tray did not warm the food as the Skylab tray did, but it held it in place with springs and Velcro fasteners. The tray was secured to the crew member's leg during mealtime (Sachin Mhalaskar et al., 2021).

5.6 Space Shuttle (1982)

In this mission, meals looked almost identical to what astronauts ate on Earth. Astronauts designed their seven-day menus selected from 74 different foods and 20 drinks. They prepared their meals in a galley with a water dispenser and an oven. Irradiated foods joined major consumables categories, primarily to make meat safer, as they had to be stored at chilling temperatures (Sachin Mhalaskar et al., 2021).

5.7 International Space Station (ISS) (1998)

The international space station (ISS) is a giant environment for living. Most consumables in the international space are canned, frozen, or wrapped in sealed packs. The fuel cells, which provide electrical power for the space shuttle, produced water as a by-product, which was then used for food preparation and drinking. However, the electrical power was produced by solar arrays on the ISS which does not produce water. Water was recycled from various sources, but was not enough for use in the food system. Therefore, most of food planned for ISS was frozen, refrigerated, or thermostabilised (heat processed or canned) and did not require the addition of water before consumption. An adapter located on the package was connected with the galley or kitchen area to dispense that water into the package. This water was mixed with the drink powder already in package. The adapter used to add water also holds the drinking straw for the astronauts. Food package was made from microwaveable material. The top of the package was cut off with scissors, and the contents are eaten with a fork or spoon. Spicy food trout turns out to be favourite ones at that time. Thus, richly flavourful items like shrimp with tangy sauce or jambalaya with garlic beans were preferred by the astronauts in the orbit (Angelo A. Casaburri, 1999).

5. Functional space food

In the recent years there has been an increasing awareness of the role of food as a tool to improve well-being and prevent and counteract specific pathologies. Specific components of food products have been isolated and proven to have beneficial effects on the body. This new vision of food has become popular with consumers and has led the food industry towards the development of foods with favorable health properties. A food so formulated is called "functional food". The addition of functional foods targeted to astronauts for consumption during space missions is advisable to mitigate the deleterious effects of space flight on the human body. Such foods would provide the appropriate nutrients to the astronauts and could also be specifically designed to be rich in ingredients with functional properties. The development of functional foods for space travel should focus on the following properties:

- High in water: High in water to fulfil the requirement of adequate amounts of fluids. The water requirement is about 2litres/day, and very hard to satisfy the thirst-quenching capacity. The consequences of the body fluid shifts are standard because of the low fluid intake.
- High in fibre content: Many, probiotics, and prebiotic fibres are recommended to reduce intestinal diseases such as constipation and the intestinal microbes
- Rich in calcium: Calcium is an essential factor in preserving bone quality and quantity. It also helps in lowering kidney stones.

- High antioxidant property: Antioxidant acts as suitable parameters for the body's defence mechanism against free radical change. Antioxidants enhance the radical change in the body and also modify them.
- Low in sodium: Sodium chloride is liable for the salty taste in the meals and also improves the shelf life of the products. Astronauts are provided with low sodium to prevent bone energy loss. Functional foods include unique ingredients that are helpful in retaining the nutritional quality of the space foods. Functional foods are low in calories and act as an immunity booster for the astronauts. Many functional foods such as extruded pasta, dehydrated beans, fruit drinks, lasagne, tortillas, and many gel-like snacks are used for astronauts.

7. Applications of food technology in the space

The development of space food has evolved over a series of manned missions into space in various types of vehicles with a wide variety. Food development for space flight has always been from a systems approach since the food has so many intricate interfaces in the closed environment. From the consumer point of view, the design goals have always been the same and are not any different from those of the general public, which include:

- It provides an adequate food system
- A safe and nutritious food system is to be developed.
- An acceptable food system is to be developed.
- It provides a system that can balance vehicle parameters
- Minimize the volume and mass of the food
- To minimize the gas vehicle emissions
- To minimize the crew time and power requirement
- High acceptability of the space food and beverages.
- Minimum time should be required for the preparation.
- It should be easy to clean up.

8. Factors considered for space food preparation

Various factors are given thought while designing the space food. Some important factors such as the space food and the atmosphere, convenience of packaging factors, and microbial attacks are widely studied during space food preparation (Sachin Mhalaskar et al. 2021).

8.1 Biological factors

The main to study the biological factors is to prevent microbial growth and prolong the shelf life of the food. It is also for the preservation of the astronaut's health to prevent them from causing gastrointestinal problems; hence to avoid such problems, sensory test by the crew members is taken into consideration. Also, hygiene practices are followed during the preparation of the space food and beverages.

8.2 Operational factors

Food processing and packaging are both parameters considered operational factors. It also includes the preparation, food storage, packaging material, and waste disposal capacity are the Restraints taken into consideration under the operational factors. The main aim of packaging material is to provide a barrier to the oxygen levels to bring about stability to the food product.

8.3 Engineering factors

Engineering factors include checking the weight of the food and the packaging factors. The engineering factor also plays an important role in storing space food. Engineering factors also include the quantity of water utilized. The food and the packaging material should withstand the temperature, pressure, external atmosphere and maintain the oxygen level to prolong the shelf of the space foods and beverages. (Naman 2017) Innovations in space food: Innovations in space food are looking forward to developing nutritional and health taking the concern for the health of the astronauts. Innovation is using friendly packaging material to avoid the destruction of the atmosphere. Innovations in the storage areas are much required as there is a microbial attack in a short period. Due to the lack of a refrigeration system available at the space station. Scientists are also looking forward to supplying fresh fruits and vegetables to the astronauts; hence NASA is taking the task of performing experiments on space gardening in the coming years. NASA has stated that it is crucial to grow plants in space to maintain the environment, which will also be beneficial for the astronauts for their survival in the coming years. NASA is also making experiments on the study of crop functioning, the development of new products, and enhancing space beverages through the alcohol industries.

9. Challenges for Space food

- One of the biggest challenges is eating in space, as well as space travel itself is the biggest challenge ever, where everything floats around. Therefore, the food needs to be prepared, packaged, and stored, especially according to the space conditions.
- Nutritionists ensure that meals taken by the astronauts provide a balance between the nutrients and the energy they obtain.
- Salt and pepper are available in liquid form because they can easily flow in space and hence cannot be sprinkled by the astronauts.
- Packaging material should be very flexible and more accessible, and it must be chosen as per the food to be packed. Packaging material should also provide space for containers.

10. Future of Space Food

In the future, NASA is looking to send astronauts to outposts on the moon and Mars. Although the target for liftoff for the moon mission is not until 2020, efforts are already underway at the Space Food Systems Lab. Scientists in the Advanced Food Technology group, led by NASA food scientist Michele Perchonok, are developing foods that are a food's shelf life for these future missions. For an initial trip to Mars, you will need products with a 5-year shelf life, "Kleoris says. The only foods that have currently shown such a long shelf life are a few thermostabilized foods, which is not enough to provide a balanced diet; Kloeris says Perchonok and her team are always looking to improve packaging materials that will provide a better barrier to water and oxygen which can cause food to spoil. This way, the shelf life for many current food items can be extended. Another area of research is developing ways to transport some foods, such as wheat, berries, and soybeans, in bulk to reduce the number of packaging materials used to minimize waste. "A 1000-day mission to Mars for a crew of six will need about 10,000 kilograms if we went with our packaged food systems." Perchonok says, "if we can save on that by growing some items, by bringing some items up in bulk, it will be a lot easier".

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