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Space food technology: Historical background, present prospective and future aspects

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Abstract
Space food technology has undergone significant advancements since the early days of human spaceflight. In the past, food was often freeze-dried or irradiated to increase its shelf life and reduce its volume, but these methods resulted in poor taste and texture. Today, space food is often packaged in rehydratable pouches and can be heated up in-flight. However, current space food technology still faces challenges such as the need for long shelf life, lack of fresh ingredients, and the need to meet the nutritional needs of astronauts during long-duration missions. In the future, advancements in food production technology such as vertical farming and 3D food printing may help to improve the taste and nutritional value of space food and make it possible to grow fresh produce on-board spacecraft. Additionally, research into the psychological effects of food in space will be crucial for maintaining astronaut morale and productivity. This review focuses on the origin and history about space food and its technology, the current methods and methodology that is being used at present, and the future advancements and opportunities that lie ahead.

Keywords: Space food; food production; food packaging; life support system; freeze-drying

Introduction
Astronauts eat a specific type of food when in weightlessness in space, known as "space food." The appropriate diet is essential for social psychology during extended space travel, which can be maintained by consuming the right nutrients. Dietary nutrition is vital to the health of astronauts' life. Small, light, portable, and able to withstand the harmful effects of radiation, vibration, and other environmental variables like low pressure, space food should have these qualities. Space food is different from regular food in terms of composition, storage, as well as in terms of nutritional content and method of consumption.

Many physiological changes, such as bone loss, decreased muscle mass, immune function, slowed intestinal transit time, and reduced intestinal permeability, which may influence food absorption, are brought on by the environment of spaceflight. By giving astronauts enough food and nutrition for spaceflight, it is crucial to guarantee their health. However, throughout the time of space travel, astronauts' dietary intake may frequently be insufficient, which can significantly lower their nutritional status and cause or exacerbate the physiological changes in the weightlessness environment that are harmful to their health. Food for space travel will therefore require constant improvement. Two objectives should guide the development of space cuisine: first, to meet the physiological needs of astronauts for survival, and second, to meet their need for psychological well-being and enjoyment throughout their protracted and challenging space missions.

Science and technology advancements have greatly increased both the quantity and calibre of food available in space. The only anatomical distinctions between spaceflight diets and those on Earth are those. Today, astronauts can eat a week's worth of completely different cuisines. Indulging in their own fast-food culture while in space, American astronauts have eaten hamburgers, salads, sausages patties, desserts, and even turkey for Thanksgiving. The Russian crew on the ISS has accessibility to a menu with more than 300 alternatives, four meals daily, and a range of options for each meal, including dry meat, broccoli and cheese, jellied pike pig, baked potatoes with almonds, etc. Japanese food predominates in Japan and includes meals like sushi, noodles, natto rice, fruit, curry steak, seafood, pig stew, and others. Astronauts can now choose from more than 100 different Chinese cuisines, including yuxiang pork, Kung Pao chicken, lotus seed porridge, steaming beef, rice dumplings, Eight Treasures rice, Chinese herbal tea, and more. The advancement of food processing and preservation technology has contributed to the creation of such a rich and diverse diet. (Jiang *et al* 2019) [14].

The crew's requirements for psychological freshness have been satisfied, but a more uniform quality assurance method also must be implemented for physiological safety.

Initially, just a small percentage of each batch of food could be utilised for space flight because a significant percentage of each batch had to be used for testing. The Hazard Analysis and Critical Control Points (HACCP) system was created in conjunction with NASA, Pillsbury, and the U.S. Government and was initially used in the 1960s considering this. This proactive approach effectively addresses the inadequacies of final product testing while offering high-quality aeroplane food. It has been recognised as the most effective method for reducing foodborne illness by the World Health Organization (WHO), and it has encouraged innovation in the food business. (Jiang *et al* 2019) [14]. Astronauts today eat as many different types of food as people do on Earth; eating has evolved from only providing for basic energy demands to, to the greatest extent feasible, gratifying their interests and psychological needs.

Space food- The Past

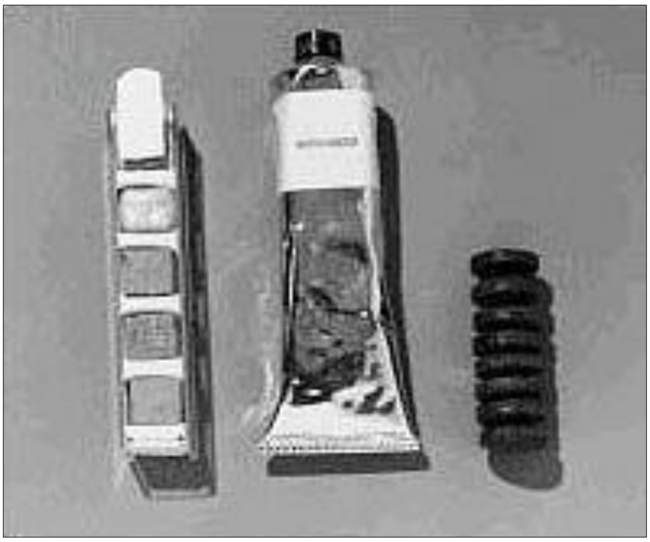
John Glenn, the first American to consume food in the nearly weightless environment of Earth orbit, found the job of eating to be quite simple but found the menu to be rather limited. Other astronauts from the Mercury mission had to put up with bite-sized cubes, freeze-dried powders, viscous liquids crammed inside of aluminium tubes. Most people concurred that the dishes weren't tasty and that they didn't like to squeeze the tubes. Additionally, freeze-dried foods were quite difficult to rehydrate, and it was important to prevent crumbs from contaminating equipment. (NASA 2020).

Mercury

The first US effort to put people in orbit around the Earth took place during Project Mercury (1961 to 1963). Two suborbital flights were followed by three orbital missions that might last up to 34 hours. There was no food on the suborbital flights. When John Glenn ate applesauce straight from an aluminium tube on the third mission of the Mercury flight in 1962, he became the first American astronaut to do so. The package's design met the needs and prevented any food from contaminating the cabin. However, the user could neither see nor smell the meal while eating, which was one of the unfavourable aspects of eating foods from tubes (like modern toothpaste tubes).

The product's texture was likewise restricted to the tube's aperture and the processing capability for filling tubes. Besides the foods in tubes, Foods in cube form were included for the Mercury missions. These 0.5-inch-tall bite-sized cubes contained a high-caloric blend of protein, high melting-point fat, sugar, fruit, nuts. Similar issues to those with the tubes also existed with these foods. The manufactured cubes didn't have the same texture or mouth feel as their familiar counterparts, although having the same initial ingredients, such as sugar cookies squeezed into sugar cubes. Although pre-flight taste tests showed that the cubed delicacies were well-liked, many cubes were sent back from the trips unfinished. The Mercury crew's meals, according to the majority, were disgusting.

During the Mercury mission period, food researchers and developers focused on calorie-dense, nutrient-rich, and tasty foods. There were no arrangements for specific food storage aboard the spacecraft because these missions were brief (Meusburger *et al* 2014) [7].



Credits: NASA

Fig 1: During the Mercury program, astronauts' food often came in tubes or bite-sized cubes.

Gemini

The 10 Gemini flights in 1965 and 1966, which had two-person teams and could last up to 14 days, were all launched. Foods that were concentrated were given priority on the Gemini program's menu because it had a weight and volume restriction and only allowed for 2500 kcal per participant. There was developed a food system that included packaging and formulas. Specifications and testing procedures for food and packaged food have been developed to provide the greatest level of security. According to the analysis's findings, the food business invented the Hazard Analysis Critical Control Point system, which is now used by the global food industry. To resist the rigours of space flight, packaging with high water condensate and oxygen barrier qualities was developed. Gemini spacecraft requirements like nutritional, sensory, and microbiological prerequisites were met by food. The crews kept eating items squeezed from tubes or bite-sized chunks. Even though the snacks passed muster in ground-based tests, astronauts lost weight during flight due to insufficient consumption (Meusburger *et al* 2014) [7].

Fig 2; Credits: Space meal package from Gemini mission 2022, Museum of Applied Arts & Sciences, accessed 13 September 2022

Apollo

The Apollo programme, which ran from 1968 to 1972 and with the specific goal of putting people on the Moon by the end of decade, was the most narrowly concentrated effort in US space exploration history. The earliest Gemini and Apollo feeding systems were extremely similar. However, by the later Apollo missions, enhanced quality and greater variety had emerged as crucial design elements for the food system.

The crew's ability to eat the food became increasingly crucial as the missions became longer. The nutrients that food provides is meaningless if it is not eaten. People also enjoy and favour variety in their diets. Later Apollo flights used retort pouches and cans as part of an enhanced feeding system. Food that has been retorted thermally is sterilised and can be kept at room temperature for a long duration. Astronauts from Apollo were the first to contain hot water, which facilitated food rehydration and enhanced meal flavour. The crew started using utensils and eating from open containers for the first time at this point as well. Apollo 8 introduced flexible packed and thermostabilized foods to the menu, ushering in the introduction of the spoon. Additionally, the Apollo crew were one of the first to consume radioactive food in space. The spoon-and-bowl package was created early in the Apollo programme as a remedy for the issue of direct package-to-mouth eating. A one-way water port was used to introduce water. The meal bar was a distinctive product and packaging created for Apollo.

It was made to be consumed by astronauts without using their hands inside their space suits. The packed bar could be reached by the astronaut's mouth and taken out in bite-sized pieces from a sleeve. Compressed fruit leather was used to make this fruit bar, which was then wrapped in an edible starch film. Most of the Apollo astronauts did not ingest enough nutrition, despite the advancements and enhancements made to the in-flight food system compared to those employed on earlier flights.

It became clear that proper food supplied to the consumer in a familiar manner is the first step toward ensuring enough nutrition (Meusburger *et al* 2014) [7].

Credits: Bettmann/Gett

Fig 3: Apollo 11 food

Credits: Bettmann/Gett

Fig 4: The Apollo 11 astronauts ate packaged beef and veggies.

Credits: Bettmann/Gett

Fig 5: Mixed dehydrated food packed for Apollo 11 astronauts.

ARMSTRONG MENU (Red Velcro) - Apollo 11 Menu

Day 1

Meal B--Beef & Potatoes
Butterscotch Pudding
Brownies
Grape Punch

Meal C--Salmon Saldd
Chicken & Rice
Sugar Cookie Cubes
Cocoa
Pineapple Grapefruit Drink

Day 2

Meal A--Fruit Cocktail
Sausage Patties
Cinnamon Toasted Bread Cubes
Cocoa
Grapefruit Drink

Meal B--Frankfurters
Applesauce
Chocolate Pudding
Orange Grapefruit Drink

Meal C--Spaghetti with Maat Sauce
Pork & Scalloped Potatoes
Pineapple Fruitcake
Grape Punch

Day 3

Meal A--Peaches
Bacon Squares
Apricot Cereal Cubes
Grape Drink
Orange Drink

Meal B--Cream of Chicken Soup
Turkey & Gravy
Cheese Cracker Cubes
Chocolate Cubes
Pineapple Grapefruit Drink

Day 3

Meal C--Tuna Salad
Chicken Stew
Butterscotch Pudding
Cocoa
Grapefruit Drink

Day 4

Meal A--Canadian Bacon & Applesauce
Sugar Coated Corn Flakes
Peanut Cubes
Cocoa
Orange-Grapefruit Drink

Meal B--Shrimp Cocktail
Ham & Potatoes
Fruit Cocktail
Date Fruitcake
Grapefruit Drink

Meal C--Beef Stew
Coconut Cubes
Banana Pudding
Grape Punch

Day 5

Meal A--Peaches
Bacon Squares
Strawberry Cubes
Grape Drink
Orange Drink

Meal B--Beef & Potatoes
Butterscotch Pudding
Brownies
Grape Punch

Meal C--Salmon Salad
Chicken & Rice
Sugar Cookie Cubes
Cocoa
Pineapple Grapefruit Drink

Credits: Ralph Morse/The LIFE Picture Collection/Getty Images.

Fig 6: Apollo 11 Space Mission Menu

Skylabs

The food system on Skylab in 1973 was noted as being by far the tastiest and most varied in all space missions. There were 72 different food options available, and the menu cycled every six days. Crews may enjoy dishes like ice cream, fillet mignon, lobster, as well as cool drinks and sweets, owing to Sky Lab's refrigerators and food heaters. (Jiang *et al* 2019) [14]. The most significant metabolic study ever out by the United States in space was part of the Skylab programme, which ran from 1973 to 1974. Skylab data continue to provide the standard nutritional data for space.

All the food was produced during a pre-flight experiment, which gave samples for examination and set baselines. Additionally, a 56-day closed-chamber test with three astronauts was utilised for the experimental diet. 37 distinct nutrients were examined in trial and flight foods. Six nutrients were kept at specific amounts for 21 days prior to flight, throughout flight, and for 18 days following flight. The most delectable and diverse food system to date to be deployed in space was the Skylab meal system from 1973. There were 72 dishes available, and the menu cycle lasted for 6 days. Skylab was the first US space mission to contain freezers, food warmers, and refrigerators. The staff could get ice cream, fillet mignon, and even lobster from the onboard freezers, and they could get cold drinks and treats from the refrigerator. A pair of scissors were included in addition to the usual fork, spoon, and knife for opening plastic seals.

Unlike earlier spacecraft, Skylab had a large interior space with space for a dining table. Eating required footholds that allowed the three-person Skylab crews to position themselves around the table and "take a seat" to eat. The dining table has built-in food heaters with timers for advanced meal preparation. As a result, the Skylab crew continued to consume the best amount of nutrients for US astronauts to date. Although the first flight launched all the Skylab program's planned food, it had been more than two years old when the last crew consumed it. The large proportion of the food was packaged in aluminium cans to prolong the 2-year shelf life. In order to minimise spilling while heating the food and to make opening in micro-gravity easier, frozen food that needed to be heated as well as some thermostabilized goods were placed in aluminium cans with a membrane underneath the lid (Meusburger *et al* 2014) [7].

Credits: nasa.gov

Fig 7: Skylabs food tray

Credits: Nasa.gov

Fig 8: Skylab Crew Members Dine on Specially Prepared Space Food

Space food – The Present

The present food supply for the International Space Station (ISS) consists of processed meals that are microbiologically safe, suitable for micro-gravity, and vacuum-packaged in a high-barrier laminate with an aluminium foil covering. Processing steps used to achieve food safety, such as freeze-drying, irradiation, and retort thermostabilising, cause chemical and structural changes that impact the food's quality and stability. The majority of vitamins are affected by processing and storage; however degradation is particular to the food matrix, processing background, shelf life factors, and packaging (Cooper, M *et al* 2017) [3].

Astronauts today eat as many different types of food as people do on Earth; eating has evolved from only providing for basic energy demands to, to the greatest extent feasible, gratifying their interests and psychological needs. The classification and description of space foods according to the types, forms, and processing techniques are provided in the next section. (Jiang *et al* 2019) [14].

1. Rehydratable: The NASA food supplies comprise both externally and internally processed freeze-dried foods, which are then rehydrated using drinkable water during the trip. Cereals and side dishes like cornbread dressing and spicy green beans are two examples of rehydratable foods. Soups, shrimp cocktail, and scrambled eggs are examples of ESA rehydratable items. The staff has access to both ambient and hot water for rehydrating these things. (Getsov, P *et al* 2020) [5].

2. Thermostabilized: This method, often referred to as the retort method, involves heating food to a temperature that kills all pathogens, microorganisms responsible for food spoilage, and enzyme activity. Pouched soups, sides, desserts, puddings, and entrees are among the things that NASA thermostabilized. Products thermostabilized by ESA include tuna, ravioli, and beef with mushrooms. (Getsov, P *et al* 2020) [5].

3. Natural form: Foods in their natural forms are readily available, shelf-stable foods. All of the items have reduced the water activity, which prevents the food from microbial growth, regardless of moisture content, which ranges from low moisture such as almonds and peanuts, to intermediate moisture such as brownies and dried fruit. These foods complete the menu by offering highly familiar menu alternatives, more menu variety and foods that don't require any preparation. (Getsov, P *et al* 2020) [5].

4. Beverages: Currently, either freeze-dried beverage mixes such coffee or tea or flavoured beverages are served on the International Space Station (ISS) such as lemonade or orange drink. The beverage pouches are vacuum sealed once the drink ingredients have been weighed. Before sealing the pouch, coffee or tea drinkers can add either sugar or powdered cream. For drinking water, empty beverage pouches too are available. (Getsov, P *et al* 2020) [5].

5. Extended shelf-life bread products: Scones, tortillas, waffles, and dinner rolls are examples of products that can be prepared and packed to have a shelf-life of up to 18 months. Breads contribute to menu variety and satisfy crew members' demand for familiar foods, much like natural foods do. (Getsov, P *et al* 2020) [5].

6. Fresh food: Foods with a short shelf life, including fresh fruits and vegetables, are offered sparingly, more for psychological support than to satisfy dietary needs. (Getsov, P *et al* 2020) [5].

7. Irradiated: Foods are not routinely processed to commercial sterility using irradiation. However, the Food and Drug Administration (FDA) has granted NASA a special exception to manufacture 9 items of irradiation beef to commercial sterility. (Getsov, P *et al* 2020) [5].

Current space food processing technologies

1. Freeze-drying technology

The process of freeze drying, also known as lyophilization technique or cryo-desiccation, involves pre-freezing wet material, sublimating frozen solvents under vacuum, and desorbing any remaining bound-water from the material matrix. Most goods, including cooked and raw animal products, can be properly dehydrated via freeze-dehydration as opposed to conventional dehydration. The product has a porous dried particle structure rather than a solid one, a natural odour and colour, and a lesser density than the original food. In addition to preserving the original nutrients, flavour, and taste of food, freeze-drying technology is also more natural and healthier because it does not require the use of preservatives (Jiang, J *et al* 2020) [9].

Ice cream, the first freeze-dried space food was created by Whirlpool Corp under NASA contract, however the dish was a little challenging to consume in space because it fragmented quickly. Today, a variety of freeze-dried dinners are utilised in space travel, including dishes from other cultures including China, India, and Mexico, with the most popular being a bowl of freeze-dried shrimp with seasoned cocktail sauce. A novel method for making "instant" ready-to-eat rice that disrupts the fundamental structure of grains by repeated freezing and thawing has also been developed in collaboration with NASA. This method enables fast rehydration of rice. The procedure involves freezing and thawing cooked rice three times in a freezer at -14 degrees Fahrenheit for two hours (Jiang, J *et al* 2020) [9].

The Italian space agency created a space food with a distinct flavour, rich in calcium and probiotics, and able to withstand the destruction of intestinal flora brought on by microgravity by freeze-drying regular and blueberry yoghurt. To create a freeze-dried dish with distinctive Korean flavours, the Korea Atomic Energy Research Institute transformed the Korean seaweed soup miyeokguk. In 2010, the soup was served aboard the Russian International Space Station after being approved as a space food by IBMP (Jiang, J *et al* 2020) [9].

Fig 9: Photograph of freeze-dried miyeokguk as a space food (Song *et al* 2012).

2. Food 3 D printing technology

The practise of using layer-by-layer printing and stack building techniques in 3D printing to manufacture food is referred to as "3D food printing." The "Foodini," the first food printer, was shaped like a typical 3-D printer but used edible materials that were extruded from stainless steel capsules rather than plastic. (Misal, Mahajan, and Patil 2015). The 3D printer is not only capable of completing intricate designs, like extremely detailed cake decoration or haphazardly organised foods, but it can also be used successfully for items that need accuracy and skill, like pizza or spaghetti (Prisco) (Jiang, J *et al* 2020) [9].

As we push the boundaries of the Earth-Moon exploration and expand space travel to Mars and beyond, mission lengths will be prolonged to months or maybe even years; as a result, new technology must be created to feed the crew with a long-term, sufficient, and appetising meal. With the help of 3D printing, relatively easy cooking operations may be completed in space. It can also collect astronauts' health data and utilise it to create food that is suitable for their needs and tastes. The Cornell Creative Machine Lab has created a 3D printer that can create biscuits for two patients with extremely different health situations that are the same form but have different calorie contents (Lin 2015) (Jiang, J *et al* 2020) [9].

The ink cartridges of 3D food printers will contain powdered nutrients from space food, such as carbs, sugar, and proteins. During three-dimensional food printing, several liquids, like milk, can also be created in form of powder and then rehydrated. During the 3D printing process, it is also possible to add vitamins or spices in powder form, which not only alters the taste of the food and improve the nutritional components. (Terfansky and Thangavelu 2013) [13].

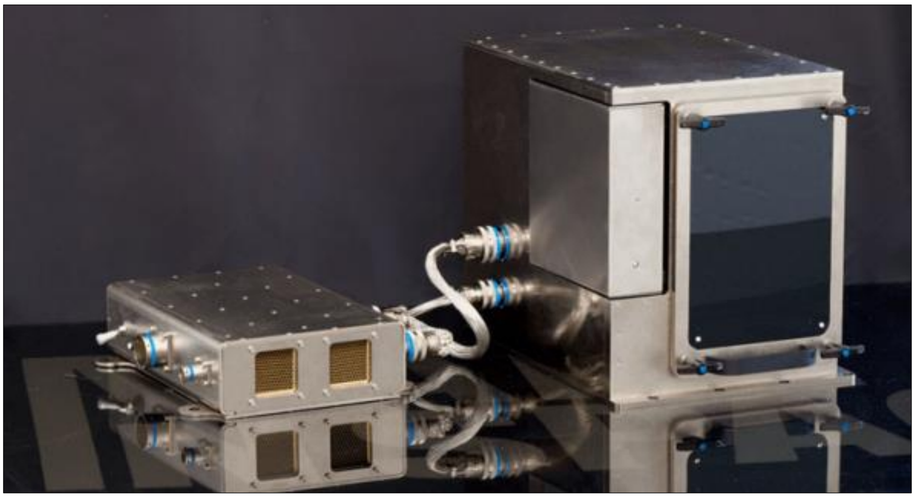


Fig 10: Photograph of Zero-G printer, available at http://madeinspace.us/projects/3dp

The growth of nutrient-rich food media and materials available for the equipment, according to NASA experts, may assist advance the objective of visiting asteroids or eventually landing on Mars (Terfansky and Thangavelu 2013) [13]. The first 3D printer capable of functioning in zero gravity was created by Made In Space, a firm based in Northern California, in collaboration with NASA Marshall Space Flight Centre. On September 21, 2014, the printer, known as the "3D Printing in Zero Gravity Experiment," was launched into orbit. One of the significant technical issues for operation certification aboard the ISS was the printer's capacity to filter harmful gases and nanoparticles. Systems & Materials Research Corporation (SMRC), an Austin-based technology company, received a $125,000 grant from the US government in 2013 to create comestible prototypes that may be utilised for interplanetary travel. (Terfansky and Thangavelu 2013) [13].

Together with the South Institute of Space Science and Technology in Shenzhen, China, Lee Kin-kee has formed the "3 D Space Food Printing Technology and functional condiment Joint Laboratory." It intends to conduct research on topics including lightweight, intelligent, and 3D space food printer miniaturisation. Additionally taken into consideration are functional condiment research and development as well as the creation of standards for related products (Terfansky and Thangavelu 2013) [13].

3. Irradiation sterilization

Many researchers have looked at the effective and promising sterilisation technique known as irradiation technology. Without warming the food, it can increase the shelf-life of space food while maintaining its nutritional value. Its remarkable benefits include ease of use, high productivity, environmental friendliness, safety, low nutrition harm, maximum food original flavour retention, and decreased chemical additives. Today, hospital diets, ready-to-eat foods, and space food are all exposed to significant levels of food irradiation (Feliciano 2018) [10]. More than 60 nations permit the irradiation of food, which processes roughly 500000 metric tonnes of food annually.

One of the methods NASA frequently use to sanitise food for space travel is radiation technology. A single dose of 50,000 rads did not alter the functional quality of flour, nutrients remained mostly unaltered, according to NASA radiation testing on flour and bread. Irradiated flour and bread performed significantly better than untreated bread six months later. This research is important because it contributes to the recognition of irradiation technology as a reliable and secure method of food preservation. The current irradiation product used on the shuttle by NASA is called steak. The steaks are prepared, sealed in a flexible foil bag with a vacuum seal, then sterilised with ionising radiation at room temperature (Feliciano 2018) [10].

The Korean Atomic Energy Research Institute has recently developed high dose gamma radiation therapy to create space food from nutrition bars, Ramen (instant noodles), and two traditional Korean dishes, Kimchi and Sujeonggwa. The kimchi's flavour and nutritional worth were ensured by the addition of calcium lactate and vitamin C. Deep freezing, mild heating, and 25 kGy of gamma radiation were used to transform the food into a ready-to-eat space food. The doses for ramen, nutrition bars, and sujeonggwa were determined to be 10, 15, and 6 kGy, respectively. During its 30-day space trip, the Russian Institute for Biomedical Problems verified the three forms of food listed above. (Feliciano 2018) [10].

Fig 11: Photograph of ready-to-eat Kimchi as a space food (Jiang, J *et al* 2020) [9].

4. High pressure processing

A technique called high pressure processing uses high pressure to treat items and produce a germicidal effect. Food microorganisms and enzymes will alter in structure under high pressure circumstances, losing their physiological activity. High pressure processing has a minimum and maximum limit of 200 MPa and 600 MPa, respectively. In the 1990s, Japan started processing juice, jelly, and jam using high-pressure sterilisation. The method has since been expanded to include the sterilisation of aquatic products, milk, fruits, vegetables, meat, salad dressing, yoghurt, and other products (Jiang, J *et al* 2020) [9].

HHP technique is frequently combined with conventional heat treatment because of equipment costs and technical limitations. The National Centre for Food Safety and Technology in the United States has developed the pressure-assisted thermal sterilisation (PATS) process, which, when compared to the conventional high temperature sterilisation process, greatly reduces the sterilisation time and improves the quality of low-acid food. To prepare low-acid items for PATS, they must first be vacuum packaged in a flexible pouch or container with a high barrier before being heated to the appropriate temperature. Compression heating is used to bring the product's temperature up to the pressure temperature. The product's temperature dropped during the decompression phase, and the finished item was cooled to room temperature. NASA conducted a study to determine the PATS food's shelf life, and the findings revealed that after three years of storage, the PATS fruits' colour and texture were superior to those in retort bags. Fruits can have a 5-year shelf life if PATS processing is combined with refrigeration. In addition, PATS fruits' vitamin content can last longer than fruits that have undergone retort processing (Jiang, J *et al* 2020) [9].

5. Microwave assisted thermal sterilization

In-depth study on microwave aided thermal sterilisation (MATS) has been done by NASA. This innovative technology enables for in-container processing and offers superior nutrient retention than more traditional methods. The disadvantages of traditional sterilising methods, such as uneven heating and edge effects, can be significantly reduced when using water as a heating medium in a microwave. Despite being a very effective way of food processing, there are rare instances where it might modify some of the ingredients. Microwave technology has been extensively used in the thawing, heating, ironing, pasteurisation, cooking, frying, drying, and other processes involving food. (Jiang, J *et al* 2020) [9].

China has developed a revolutionary hybrid technique that combines microwave sterilisation, flexible packaging, and vacuum low temperature seasoning to address the concerns with canned food's subpar flavour and traditional thermal treatment's intensity. Assuming that long-term storage at room temperature will be secure, the odour of auxiliary and raw materials are removed, and the flavour and taste of food after sterilisation is kept to the greatest extent possible. In order to determine whether applying less heat during processing could protect food micronutrients and extend shelf-life, NASA looked at the retort process and microwave assisted thermal sterilise. Although the original colour and feel of the MATS product were superior, these advantages did not last because the non-metallic packaging material likely did not offer a strong enough oxygen barrier. There was no noticeable difference between the MATS product and the result from the retort processing in terms of vitamin stability. Future study may focus on enhancing the packaging film used in MATS processing and optimising the packaging's dielectric characteristics formula in order to achieve the main course and soup's 5-year shelf life in wet packages. Additionally, methods for strengthening vitamins and lowering storage temperatures must be developed (Jiang, J *et al* 2020) [9].

Packaging of current space food

Requirement of space food packaging

Space food packaging's main goal is to preserve and contain the food. However, the packaging should also be portable, simple to discard, and helpful in the process of getting the food ready for eating. A bar-coded marking on the box also enables the keeping track of an astronaut's diet. The food's labels also provide English and Russian preparation instructions. Cans and tins are used to package a lot of the food used in the Russian space programme. These are opened using a can opener, heated using electro-resistive (ohmic) techniques, and the food within is consumed immediately. Soups in Russia are watered and eaten straight from the packaging. NASA uses freeze drying or retort pouches to package food for space travel. To keep them in place, they are also packed in sealed canisters that fit onto trays. The trays have slots for holding a beverage pouch or cutlery in the microgravity condition and straps on the underside that astronauts can use to tie the tray to an anchor point like their legs or a wall surface.

1.4.2 Different types of space food packaging

1. Edible film

As ingredients for edible films, starches, proteins, lipids, polysaccharides, and composite materials are widely used. Some of the uses for edible films include the packaging of flavouring powder in fast food and the preservation of meat, frozen items, fresh fruits, vegetables, and baked goods. The edible packaging film essentially avoids the change in the flavour and texture of food products during storage and transit, protecting food quality and prolonging the shelf life of food. It does this by limiting the migration of water vapour, solute, gas, and fragrance components. Additionally, coating can be used to attain the goal of nutrition strengthening. Beeswax, paraffin, titanium dioxide, and non-toxic, biodegradable resins are some examples of coating materials. Coatings like resins based on jade have their safety authorised by the Food and Drug Administration (Jiang, J *et al* 2020) [9].

NASA has provided funding to the Southwest Research Institute to develop a polypeptide film that might isolate pathogens, limit water loss, and stop the food from rupturing. The developed samples have great barrier properties, however because of their high tensile strength, they cannot be used as food coatings. They have been utilised to make short-term artificial skin instead. The barrier performance is not yet up to the norms of long-term space travel and manned missions, the edible film performance is poor, sealing performance, the tensile strength, water resistance, and high temperature resistance are all low. These problems result from recently developed technology. increasing the food's shelf life. The shelf life of 3-5 years required for food for space travel is far from being met by edible films (Jiang, J *et al* 2020) [9].

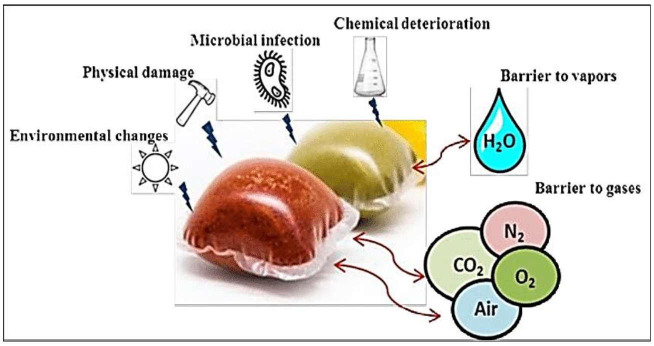


Fig 12: Source: (Hasan *et al* 2020) [6]

2. Metal can

Tinplate, aluminium alloy, and other types of metal can packaging have good barrier qualities that often extend the shelf life of food by up to three years. Most of the food was stored during the Skylab programme in metal cans to preserve its two-year shelf life. Foods that have been frozen or heated to a specific temperature are packaged in metal cans with a headspace under the lid to avoid spillage. To endure absolute pressure differences of 14.7–5.0 lb/in2 between the ground and space, the aluminium canisters will be contained in a different tank. Each can is drained and nitrogen flushed a minimum of three times with the goal of lowering the oxygen content of the headspace gas before sealing. Currently, manned missions make use of this packaging technology, including the metal packing form, which was used to package food that Russia donated for the international space station. This packaging is thick yet has an excellent barrier. This package form is inappropriate for use in long-manned flying missions due to the weight of the packaging and the challenges involved in disposing of waste (Jiang, J *et al* 2020) [9].

Fig 13: Source: https://humans-in-space.jaxa.jp/en/life/food-in-space/japanese-food/detail/001008.html

3. Retort pouch

Retort pouches, which are constructed of a laminate of malleable plastic and metal foils, are used to save space and reduce mass. To replace tinplate cans for use in warfare, the soft packaging was created by the United States Army Natick Research and Development Command, Reynolds Metals, and Continental Flexible Packaging. Such packed food has a lengthy shelf life and can be stored at room temperature. It may be used easily and can reduce the energy required for preservation by being consumed hot or cold. It took the place of rigid rectangular rehydratable packaging, and to reduce waste volume, a waste compactor that was compatible with the packaging was created. Foods that have been irradiated or thermostabilized are frequently packaged in flexible pouches. Products that have undergone retort processing can guarantee food safety and nutritional value while also improving consumer acceptance. This packing technique offers a great chance of keeping food's acceptable sensory texture during its three to five-year storage term. There is almost little oxygen or moisture permeability since the container is built of a quad-laminate of polyolefin, polyamide, aluminium foil, and polyester. (Jiang, J *et al* 2020) [9].

In contrast to the non-metalized film with the maximum barrier, the metalized film overwrap significantly slowed the process of the rancidity of butter cookies, according to NASA's research. by doing a complete physical property assessment, sensory evaluation, and nutritional analysis to establish the best-before date of these foods, While fruits and desserts are projected to last for 1.5–5 years, dairy products for 2.5–3.25 years, and vegetables, starches, and soup ingredients for 1-4 years, it is predicted that meat products and other imported vegetables will have a shelf life of 2–5 years without refrigeration. (Jiang, J *et al* 2020) [9].

SAMPLE CREW MENU ON THE INTERNATIONAL SPACE STATION*

Meal 1	Meal 2	Meal 3	Meal 4
Day 1			
Cottage cheese with nuts (R) Chicken with prunes (T) Moscow rye bread (IM) Apple-peach juice with pulp (R) Tea without sugar (R)	Jellied pike perch (T) Peasant soup (R) Pork with lecho sauce (R) Borodinskiy bread (IM) Kuraga (IM) Apple-black current juice with pulp (R) Tea without sugar (R)	Shrimp cocktail (R) Beef steak (I) Macaroni and cheese (R) Fruit cocktail (T) Strawberry drink (B) Tea with lemon (B)	Granola bar (NF) Almonds (NF) Peach-apricot drink (B)
Day 2			
Mexican scrambled eggs (R) Applesauce (T) Oatmeal with brown sugar (R) Grits with butter (R) Orange-pineapple drink (B) Strawberry breakfast drink (B)	Chicken noodle soup (T) Teriyaki chicken (R) Tomatoes and eggplant (T) Strawberries (R) Lemonade with A/S (B)	Pork with potatoes (T) Rossiyskiy cheese (T) Moscow rye bread (IM) Honey cake (IM) Currant tea without sugar (R)	Sweet almonds (NF) Hard chocolate (NF) Grape-plum juice (R)
Day 3			
Omelet with chicken (T) Sweet peas with milk sauce (R) Borodinskiy bread (IM) Apple-apricot bar (IM) Tea without sugar (R)	Pike perch in Baltika sauce (T) Pureed vegetable soup (R) Beef goulash (T) Mashed potatoes with onions (T) Moscow rye bread (IM) Apricot juice with pulp (R)	Apricot juice with pulp (R) Rice pilaf (R) Asparagus (R) Tapioca pudding (T) Tea with lemon (B)	Cheddar cheese spread (T) Crackers (NF) Candy-coated chocolates (NF) Pineapple drink (B)
Day 4			
Breakfast sausage links (I) Cinnamon roll (NF) Grits with butter (R) Granola with raisins (R) Orange juice (B) Cocoa (B)	Cream of mushroom soup (R) Grilled pork chop (T) Mashed potatoes (R) Macadamia nuts (NF) Tea (B)	Pike perch in Baltika sauce (T) Beef with vegetables (T) Moscow rye bread (IM) Prunes stuffed with nuts (IM) Strawberry tea without sugar (R)	Sweet almonds (NF) Vostok cookies (NF) Peach-apricot juice with pulp (R)
Day 5			
Rossiyskiy cheese (T) Chopped pork with eggs (T) Wheat bread enriched (IM) Quince bar (IM) Apricot juice with pulp (R) Tea without sugar (R)	Jellied pike perch (T) Pureed vegetable soup (R) Meat with barley kasha (T) Moscow rye bread (IM) Apple-plum bar (IM) Apple-peach juice with pulp (R) Tea without sugar (R)	Beef with BBQ sauce (T) Potatoes au gratin (R) Italian vegetables (R) Dinner roll (NF) Shortbread cookies (NF) Tea (B)	Tuna salad spread (T) Crackers (NF) Lemonade with A/S (B)
Day 6			
Grits with butter (R) Sausage pattie (R) Seasoned scrambled eggs (R) Pear (T) Plain yogurt (T) Tea (B)	Vegetarian Vegetable soup (T) Smoked turkey (I) Candied yams (T) Peach ambrosia (R) Tropical punch with A/S (B)	Chicken with rice (T) Stewed cabbage (R) Moscow rye bread (IM) Prunes stuffed with nuts (IM) Apricot juice with pulp Tea without sugar (R)	Russkoye cookies (NF) Apple dessert (T) Grape-plum juice with pulp (R)
Day 7			
Chopped pork with eggs (T) Assorted vegetables (R) Rossiyskiy cheese (T) Visit crackers (NF) Borordinskiy bread (IM) Kuraga (IM) Apple-black currant juice with pulp (R)	Peasant soup (R) Spiked pike perch (T) Beef with vegetables (T) Moscow rye bread (IM) Apple-plum bar (IM) Apple-peach juice with pulp (R) Green tea without sugar (R)	Lasagna with meat (T) Creamed spinach (R) Corn (R) Brownie (NF) Tea (B)	Dried peaches (IM) Macadamia nuts (NF) Orange-mango drink (B)
Day 8			
Waffles (NF) Scrambled eggs (R) Grits with butter (R) Bran Chex (R) Apples with spice (T) Orange juice (B)	Split pea soup (T) Barbecued beef brisket (I) Southwestern corn (T) Peaches (T) Tea with lemon (B)	Bream in tomato sauce (T) Tokana meat and vegetables (T) Moscow rye bread (IM) Honey cake (IM) Kuraga (IM) Apricot juice (R) Tea without sugar (R)	Hazelnuts (NF) Plum-cherry dessert (IM) Peach-apricot juice with pulp (R)

* During the 5-mo stay on the International Space Station, the crew will be on an 8-d rotation system for meals. The menu includes the meals that will be served for each 8-d period. After each period ends, the crew's meals will begin again at day 1. This rotation will continue until the crew leaves the station. (B) beverage; BBQ, barbecue; (FF) fresh food; (I) irradiated; (IM) intermediate moisture; (NF) natural form; (R) rehydratable; (T) thermostabilized.

Fig 14: Source: "NASA - Food for Space Flight". NASA.gov. NASA. 26 February 2004. Retrieved 3 March 2020

Future aspects of space food technology

1. Nanotechnology
Nanomaterials have a wide range of potential uses in the aerospace sector since they may be used to create food packaging that has characteristics like high strength, strong barrier, low weight, and multi-function. The nanoparticles present in composite packaging can meet the demands of space-saving food packaging materials. Nanomaterials can extend the shelf life of food by up to three years thanks to their strong barrier, high flame retarding, and high thermal stability qualities. The key research areas for polymer nanocomposites were the synthesis of polyethylene, polycarbonate, PAS, vinyl alcohol (EVOH), polypropylene (PP), polystyrene, poly (caprolactone), and poly (ethylene terephthalate) (PET). Additionally, to higher gas resistance, the ability to minimise oxygen, water vapour diffusion, volatile food aroma, and polymer nanocomposites also offer great physical qualities (Jiang, J *et al* 2020) [9].

2. Hurdle technology
Technology can also be used to improve food packaging. If factors like different storage temperatures, ingredient source, processing, formulation, packaging, and preparation methods are combined with the hurdle approach, it will be simpler to regulate food quality and nutrition. Every 1, 3, and 5 years for a period of seven years, NASA assessed 16 typical foods from the International Space Station as needed. Among the analysis indices were colour change, nutrition, sensory quality, texture, and water replenishment rate. Both before and after processing and storage, the packaging film's mechanical integrity and barrier performance will be evaluated. Processing, formulation, and storage are possible if tested barriers are sufficient. To attain a five-year shelf life, combinations will be individually identified for processed food matrices (Jiang, J *et al* 2020) [9].

3. Inert gas flushed packaging
In addition to employing certain packaging materials, using packaging that has been flushed with inert gas can prolong the shelf life of food. NASA created a method for maintaining the appearance and flavour of fresh bread that included cleaning the box with 70% ethyl alcohol, flushing the bread and container with nitrogen three times, and then individually wrapping each loaf of bread in a sterile environment. Bread samples can be kept without mould for more than 14 weeks (Jiang, J *et al* 2020) [9].

4. On-orbit food preparation system
Space food is gradually moving toward increased production volume and variety diversification with the industry's rapid growth. The packed and processed food system dominates the food supply method currently. This model is constrained not just by the spacecraft's uplink load capacity, but also by the crew' available flavour and variety options. It is challenging to have a satisfying eating experience that is comparable to what one has every day. With present food stabilisation methods, space food quality and nutrition decrease to unacceptable levels in two to three years. Future exploration expeditions will need a food system that can be stored for five years while still being safe, palatable, and nourishing. In terms of Mars exploration, the US and Russia are dominating the world (Jiang, J *et al* 2020) [9]. Russia just completed the MARS 500 human Mars simulation project, and the United States recently completed the successful landing of its Mars exploration vehicle there. Space exploration has progressively entered the Mars age. Long-duration manned spaceflight missions may entail stays on the moon or other planetary surfaces and last up to 2.5 years. Food for the expedition is expected to have a shelf life of five years and may be transported to Mars before the crew arrives. Only 7 of the 65 thermostabilized meals now offered on menus, according to a NASA assessment, are expected to remain delicious after 5 years of preservation (Jiang, J *et al* 2020) [9].

With the advent of 3D printing, a new method of food processing is now possible for on-orbit space missions. The main goal of 3D printing food is to preserve it for a long time by using edible raw materials when people live in space, not merely to make it tasty. The usage of 3D printing in space could reduce the need for numerous materials. The form, texture, and flavour might all be improved with a 3D printer. Currently, NASA is conducting preliminary study on the technology for processing food while in orbit and has created a prototype based on the concept (Jiang, J *et al* 2020) [9].

5. Life support system
Life support systems will be one of the major areas of research for aerospace companies in the ensuing projects. NASA developed the environmental control and life support system, or ECLSS. In order to control the ecological life support system in a closed space environment, the idea of using eatable veggies for salad preparation on spacecraft has been proposed. Space agencies are currently looking into whether it would be possible to cultivate vegetables aboard the International Space Station. Initially, NASA examined red rose lettuce, Zinny, tomatoes, and cabbage. The life support system cannot exist without greenery. To increase food variety and help crew members meet their needs for vitamins and dietary fibre, green plants can be used. Eating a vegetable high in antioxidants also helps to lessen the crew's exposure to radiation harm from space. In addition to their nutritional value, vegetables are seen as a desirable option for enhancing living conditions on board and offering the crew psychological advantages. To supply a temporary source of vegetable food and entertainment, the international space station (ISS) has successfully installed a small salad maker with the name LADA. Many scientists are working on the development of onboard salad producing facilities (Jiang, J *et al* 2020) [9].

6. Animal breeding in space
The scientists propose that enough animal proteins should be consumed to ensure the astronauts' health, and that the metabolism involved in acquiring animal protein can be coupled with material circulation in a closed system. As a result, numerous nations have conducted a wide range of studies on animal reproduction in space. Fish and amphibians make excellent space food because of their brief life cycles. The majority of fish currently chosen for research are carp, tilapia, swordtail fish, rainbow trout, etc (CNR 2018) [2]. Sea urchins, snails, and salamanders have all been examined in Europe and Japan. Space feeding is still in the development and experimental study stage, though, because these creatures are sensitive to the conditions of their feeding, particularly the presence of living water (Jiang, J *et al* 2020) [9].

Insects are potential candidates for life support systems, according to Chinese researchers who are adopting a new strategy. Large animals like cows and sheep are not suitable, according to prior tests. Because of the cramped and constrained environment, lonely experimenters create sentiments in animals they feed every day, and if they somehow end up being eaten by their companion animals that rely on one another for survival and feed them every day, there will be significant psychological changes. (CNR 2018) [2].

Future of ISRO in its Gaganyaan mission

It will undergo testing during the two unmanned missions planned by the Indian Space Research Organization before the final Gaganyaan manned trip (ISRO). The scientists working on space food are predominantly in their 40s to 45s and have expertise in food technology, microbiology, and biotechnology, according to sources within the Defence Research and Development Organisation (DRDO). DFRL is developing a number of technologies for the Gaganyaan mission, including a food waste disposal system, a food rehydrating system, a liquid dispensing system, and a meal warmer to name a few. The plan right now is to make food that can be consumed in space for a week.

In September 2019, DFRL, under the direction of Dr. Anil Dutt Semwal, began work on the Gaganyaan mission after reaching an agreement with ISRO, according to DRDO sources. The lab receives frequent feedback from ISRO regarding the requirements to be upheld when creating space food. For its part, ISRO has consulted Wg Cdr Rakesh Sharma (Retd), the country's sole astronaut, for advice on several manned flight-related issues, a DRDO official said. It's interesting to note that DFRL first became aware of the need to manufacture space food during Rakesh Sharma's expedition in 1984. Then, it had offered freeze-dried (ready to reconstitute) pineapple/mango juice powders and RTE mango bars. These RTE items, which are suitable for space missions, were always lightweight and close to fresh and would rehydrate instantly.

Challenges present

The development of space food that satisfies very strict quality standards is fraught with difficulties. When creating food for space missions, scientists must assure nutritional adequacy that satisfies macro- and micronutrient requirements. The procedure is made more challenging by the need to meet quality requirements such low volume, light weight, quick preparation, convenience of consumption, low fragmentation, high acceptability, wholesomeness, gastro-intestinal compatibility, stability, variety, little residue, and suitable packaging. The tasks that provide more challenging challenges include designing appropriate liquid delivery systems, rehydrating and reconstituting systems, food heaters, and food waste containment bags.

Quality aspects

Food in space is being treated for stability and a long shelf life. Additionally, the processing conditions were standardised to meet the microbiological goals set for each product group. Food will eventually need to go through a series of quality checks. The quality control plan, which is well-documented, contains details on the testing. There is many testing for the food and the packaging used in this. The packaging material's inflammability is a crucial factor. The pouch contents can even be heated using a food warmer or heater. Quality checks will make sure that the meal is sufficient to meet the macronutrient (fat, protein, and carbohydrate) and micronutrient (protein, fat, and carbohydrate) requirements (minerals, vitamins, and fatty acids). Standard microbiological chemical criteria were examined both internally and externally by organisations authorised by the National Accreditation Board for Testing and Calibration Laboratories in order to assess the products' stability and safety.

The Menu

According to reports, DFRL goods have undergone thorough macro-micro nutritional analysis, sensory evaluation, microbiological safety and acceptability as per NASA criteria in order to be vetted for their space worthiness for the Gagaanyaan mission. The astronauts' calorie needs have been taken into consideration when creating a comprehensive cuisine.

The extensive menu created using retort processing technology consists of sooji halwa, shahi paneer, vegetable pulav, vegetable biryani, chicken katti rolls, egg rolls, dal makhani, chicken biryani, paneer rolls, and sweet corn rolls, as well as potato-stuffed parotha, rajma chawal, sambar chawal, dal chawal, kadi chawal, preserved chapaties along with oral rehydration solution (ORS).

The astronauts have the option of pineapple juice powder, carrot/cucumber, or chicken shreds on the freeze-dried section. The menu also includes quick meals like jiffy upma, khichidi, moong dal halwa, coconut chutney, and idli sambar. Mango/lemon pickle, dates bar, chocolate bar, salted almond, cashew, and combo tech processed dry fruits are all available in the snack section along with fruit and nut bars, Omega-3 rich bars, dates bars, chocolate bars, and mango bars. Mango nectar, coffee, and tea will probably all be available in the area. The packaging material's design, volume, and packing size have all been standardised, along with its qualification and specification standards. To accommodate the micro gravity conditions, the water dispensing design has been adjusted for potable water in pouches.

More thought has gone into the liquid distribution system's design, and the complete assembly has been made leak-proof. By doing this, you can stop the liquid from leaking when it's not being drank. The assembly was created by scientists utilising a valve-style opening and closing technology. A food warmer specifically made for space travel provides a core temperature of 60–70 °C in an average of 8–10 minutes. For instant meal products, a prototype of an in-pouch rehydration device has also been developed. Appropriate biological solid waste treatment is being planned for the crew module.

Fig 15: Source: https://www.onmanorama.com/news/india/2020/08/27/gaganyaan-manned-flight-food-warming-dfrl-mysuru.html

Conclusion

Since the introduction of the first tubed meals, significant progress has been made, and as longer-duration missions are carried out, more progress will be made. A lot can happen in the years that will elapse before the envisioned future missions that will include stays on the surfaces of planets or the moon. On Earth, recycling concerns that are being addressed for planetary missions are relevant. The field of food and nutrition research is still investigating how to preserve our physical and mental health. This research focuses a lot on food and its constituent parts. Once their health benefits have been established, these foods, also known as nutraceuticals or pharmafoods, may be regarded as parts of the long-duration mission food system. It is difficult to foresee how the food system will change. But it will be made secure, nutritious and acceptable with the advancing technology that is taking place in the field of food science and particularly in the advancement of space food technology. These advancements will provide great hope for the future of space exploration in long term flight missions and hopefully inter-planetary travel.

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