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Space Food Technology: Production and Recent Developments

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ABSTRACT

Space food is a range of food products, especially created and processed for the utilization of the space explorers.

The food must necessarily provide balanced nutrition for astronauts working in space, but at the same time it is important that it must be very convenient to store and prepare in the zero gravity environment. Since the space missions are of a very long duration, the food to be consumed needs to be processed and packaged in such a manner that it does not spoil in due course of time.

Therefore various methods of processing and packaging the food, in order to make it fit for consumption in the weightless environment have been developed and scientifically tested by the leading organizations of the world. With the advances in technology (appropriate packaging and convenient on board systems), a complete elaborate menu is now available for the astronauts, enabling them to enjoy a multi course menu as per their body requirements.

The preparation and consumption of the food in a weightless environment is a very tough challenge in front of the food scientist and technologists.

Keywords : Space Food, Food science and Space Food Technology

1 INTRODUCTION

Space exploration is done by combination of old and new emerging technologies, which help us, discover the unknown facts and mysteries of the celestial bodies in space. This exploration is done by both astronomers through telescope, also by robotics spacecrafts that go up in the space to collect the desired information. With the advancement in the technology it has been possible that **space crafts with humans** are now being send up in the space to get the most authentic and crucial details about the desired celestial body.

Though the observation of the space bodies in space (astronomy) is present since a very long time, it was because of the development of the huge and dependable technology based rockets and spacecrafts during the mid-twentieth century which made human exploration of the space a reality.

These Space missions are usually done:

- To discover recent advancement in the technology and space
- For National pride
- For developing friendly relations between two nations (Joint Missions)
- Predicting survival of humans in other bodies except Earth
- Security benefits and details regarding other nations (Satellites)

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1.2: Survival of Humans in Space

During ling sea voyages, travellers and explorers used to develop methods for preserving food and carrying it enough for their survival. The main problem that they faced was of food preservation during their journeys, this used to lead to huge food wastage and also resulting in very less amount of food for their survival.

Explorers like Columbus, Cook, and Magellan carried foods preserved in brine and syrup for their longer shelf life.

Recent advancements have made it possible to preserve food by refrigeration and canning which is a huge breakthrough in the field of food preservation.

In the 1960s, NASA with its advance technology was successful in sending men into space. But even after many years of this discovery, Space food took years to be perfected.

Human in outer space survive by consuming preserved food (by various techniques) which is packaged in a special manner for it to sustain in zero gravity environment.

Differences between the foods preserved for space and land are enormous while we can afford a heavy weighted food material to be present at our disposal in grocery stores, the foods that are taken along in the space missions need to be light weight.

We can have an elaborate method of consuming a ready to eat food on land but the same in space needs to be compact and simple to be consumed. The priority to maintain taste and nutrition remain same for land and space.

The most important aspect of the space food that makes its preservation different from that of the land food is its extremely long shelf life; the food must sustain long hours without refrigeration.

Another point of difference between the two is its packaging and design. the space food must be properly sealed and stored so that it may not float around the space in the zero gravity atmosphere. Even improper storage of simple things like bread crumbs can prove to be lethal to life of the astronauts.

Loose pieces of food can block and clogs the shuttle openings; they can go inside the astronaut’s mouth, nose and eyes causing severe health concerns. Liquid foods can also create chaos and mess within the shuttle since it can float away and cause serious damage to craft and machinery.

1.3: First Space Foods

Onboard on Friendship 7 mission in 1962, John Glenn was the first American astronaut to eat food on board. At that time it was not yet known whether humans can consume and digest food in space. The scientists were not sure about how would the body enzymes and nutrients react to a zero gravity atmosphere.

Glenn's first consumption was that of the applesauce and xylose sugar tablets with water, which thus was a historic meal in itself; it confirmed that humans could eat, swallow and digest food in space

In the early 1960s, Mercury space food was based on Army rations and this consisted of simple pureed food packed in aluminum tubes like toothpaste and was consumed through a straw although there were no problems in eating drinking and chewing, the food that was consumed was not considered to be tasty.

Beef and Vegetables were also a part of their meal in their mercury mission, Glenn and his comrades were provided with a paste of both which they could

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squeeze and eat directly into their mouth

Astronauts exert less energy while performing their work as compare to what they exert on earth. Gemini mission astronauts were given 2500 calories per day which is less than that of the normal intake of 3000 calories. The foods having extremely high moisture content of ninety nine percent were reduced by moisture content to make them light weight thus the average content of proteins was 17 percent, 32 percent of fats and 51 percent of carbohydrates.

The U.S. Army Laboratory in Natick, Massachusetts and NASA prepared and packaged the space food for Gemini and Apollo in collaboration with Whirlpool Corporation.

The first solid food that was eaten in space was that of Gemini 3. John Young carried two packaged meals with him on space that was for a five hour mission as a sample.

He surprised his fellow astronauts by presenting before them a corned beef sandwich on rye that had been purchased in Florida. However the sandwich was not a success since it started producing crumbs

Many other missions like that of Apollo 8 and 11 brought about revolutionary changes in space food.

2 PRODUCTION OF SPACE FOOD

The space food did not evolve in days or months, it took years for scientists and technologists to understand the practical problems of the food which is on board. There are many methods for the production of Fit to be Consumed Space Food.
The space food is generally divided into following groups:

2.1: Freeze Dried or Re hydratable foods: Moisture is removed from the food during packaging food materials like Soups, casseroles, scrambled eggs and breakfast cereals are packaged in this manner. As the time passed technology grew more advanced and by the time Gemini mission (1965) was launched the food became tastier. The astronauts got this choice of selected from a wide variety of food which included seafood, turkey meat and cream of chicken soup with a dessert.

The freeze drying area must be approved by USDA. The pre requisites for this include the storage and receiving section for raw materials , a food cooking area and finally a large area with lots of large freezing and drying chambers followed by a packaging section. The facility also includes a research and development lab where in new improved methods of freeze drying are discovered the food is then finally sent to a test kitchen where in it is checked for the final quality parameters of.

The freeze drying process varies many time temperature coefficients along with many combinations of pressure.

Testing and preparation of Freeze Dried Food

- The food is first checked for bacterial counts and spoilage.
- Some food items must be cooked before freeze drying .Thus they are usually bought in small cut pieces. Already cut, pitted, and peeled, fruits and vegetables are usually purchased. These fruits and vegetables are washed by spray of water. Some quickly scalded or blanched vegetables, like peas and corn are used before freezing.

  Pre-brewed concentrated liquid for coffee is purchased as the aroma of coffee is what is most appealing in the product. To improve the aroma a small amount of coffee bean oil is added to the liquid the oil is not removed when the product is dried

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Freezing

The food pieces are then spread out on a even metal trays that are staked over each other 20 to 30 at a time in a wheeled trolley for the food that is already precooked and frozen the trays are pre chilled to prevent thawing of the frozen material. For material like coffee, it is poured in a shallow pan.

These trolleys are then led into a large ,walk in cold freezer where the temp is -40^{o}C.in this temp the food quickly freezes, these trolleys are kept their till the time to dry them into the drying chamber reaches

Drying

The trolleys are then led into a vacuum drying chamber. For liquids like coffee, the frozen coffee is first grinded into small particles in a low-temperature grinder machine. With semi-elliptical ends, the drying chamber is a large, long, horizontal cylinder one end of which is closed and the other open.

This procedure is called as Sublimation. In sublimation, a solid material is transformed into gaseous state without changing into liquid state. In case of freeze dried food, the ice crystals present in the frozen food material are transformed into water vapor without changing into liquid water.

In the chamber, drying is done by removing the air with a help of a vacuum pump to decrease the pressure till about 0.036 psi (0.0025 bar). The temperature of the food is increased to about 100°F (38°C) by conduction heating passing through the bottom of the trays, radiation is absorbed from heat lamps, or microwave heating.

When the chamber is made air free, the pressure is reduced below the threshold at which water can coexist in a solid, liquid, and gaseous (vapor) state. This point is known as the triple point of water.

Once the pressure falls less than this point, the heat changes the air crystals that are trapped, directly to water vapor. The vapor is withdrawn and by condensation within the chamber food is left behind.

The dried food is now filled with tiny voids (like holes), like a sponge, where the crystals of ice were once present. This not only makes it easier for the food to be reconstituted when it is prepared for consumption by the consumer, but even the dried food retains its original size and shape. The time of this drying process differs. Freeze-dried liquids take only 4 hours to prepare while others may take 12 hours or more.

2.2: I**ntermediate moisture foods**: these are those types of foods in which some moisture is removed and the rest is not. Foods like dried peaches, pears and apricots are examples of intermediate moisture foods.

(IMF) is regarded as one of the oldest food preserving method tested by man. In this method the mixing of various ingredients to attain a given A_w that allows a safe storage for a long time but at the same time it maintains the eating quality of the food, but this work was only done on an empirical basis.

This work done by food scientists and technologist approximately 30 years ago, in the search for convenient stable shelf life products by removing water, resulted in the modern intermediate moisture foods (IMF). These foods have a high dose of preservative and humectants added to stop the growth of microorganisms. It is since then; this category of foods is subjected to continuous research and development.

2.3: Thermo stabilized foods: These foods are processed by heat at high temperature to destroy bacteria and other micro organisms so they can be stored at ambient growth temperature.

Foods like fruits, pudding and tuna fish are preserved in this. Dehydrated foods are the most well known

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space food groups thermo stabilized foods rank second in the preference, these are heated to destroy harmful bacteria and enzymes that cause food spoilage, the biggest advantage of these food is that they don't use any of the water available on the shuttle which is in a limited quantity. These foods are fast, easy and less time consuming to cook because they only need to be warmed (re heated) before eating.

2.4: Irradiated foods: Like thermo stabilized foods, these foods have been preserved by killing harmful bacteria and organisms .they come in come in flexible pouches having food that is ready to eat. The only difference is the process that is used to sterilize the food. Irradiated food is exposed to ionizing radiation from gamma rays or electron beams for a specific length of time determined by the type and content of food.

Irradiated food can include any food group from fruits and vegetables to meat. Despite the use of radiation, these food do not raise the risk of cancer for those eating it. The World Health Organization and American Medical Association have labeled them as fit to be consumed

2.4: Natural form foods:, nuts, Granola bars and cookies are examples of food with a naturally long shelf-life. They are simply packaged in ready-to-eat pouches.

2.5: Fresh foods: These are the foods available for space flight for some initial days of the mission .Fruits and vegetables that are sanitized by chlorine are packaged in a simple plastic bags to preserve their freshness are loaded in the shuttle. But since there is no refrigeration onboard in the shuttle, these foods must be consumed within the first two to three days of the mission to prevent them from spoilage.

2.6: **Condiments:** All condiments are served in liquid form, like salt and pepper. In order to make it easy for astronauts to handle it while pouring, the salt is dissolved in water as brine and the oil suspension of pepper is used.

3 NUTRITION AND SPACE FOOD

3.1: Introduction: The crew of the shuttle has a huge role to play in the selection of the food to be carried to the space.

The **Space Food Systems Laboratory** is visited by the crew five months prior to the mission. In the lab, the crew acts as a food critic and after sampling 20 to 30 food items they rank them on a 1 to 9 scale in basic sensory attributes like appearance, colour, smell, taste and texture. Any food that scores a 6 or above can make it to the menu.

However what they chose is not finalised until and unless a dietician check the menu approved for proper body nutrition.

The space shuttle usually has about 3.8 pounds of food, including 1 pound of packaging, per astronaut per day of the mission. They get three meals a day, and some snacks. A back-up **Safe Haven food system** is also there which provides an extra 2,000 calories per day, per astronaut. It's designed to uphold the crew for an additional three weeks in case of crisis.

3.2: Body Changes affecting Nutrition:

When the space flights were of less duration nutrition was never a point of concern, it was only thought about when the space flights began for long hours.

When the environment is changed our body reacts in very different way, there are numerous changes that physiologically occur in our body as oppose to those environmental changes such as zero gravity and space.

The common changes that are responsible for some drastic changes in the body include elevation of carbon dioxide content from 0.1% to 1%. Removal of

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atmospheric blanket leads to high radiation exposure and disturbance of the normal body clock.

Many other psychological changes occur in our body that affect the food intake level as desire to eat is curtailed and food acceptance becomes a serious problem. These psychological changes include interactions among small groups thus less social life, extreme workload leading to increased stress levels, no private time and space leading to irritating behavior. These small issues sum up to affect the food acceptance level were astronauts don't feel like eating thus leading to poor nutrition.

Physiologically the following changes occur in our body

1. Abruptive shifts in fluids of the body
2. Changes in the blood due to water content disbalance
3. Lack of Gastrointestinal bacteria leading to poor digestion
4. Poor separation of gases between stomach and intestine
5. Fall of the GI track holding time leading to disruptive blood flow in body

During the first few days of the space travel the astronauts experience a dizzy and nauseatic stimulation in body generally termed as motion sickness which leads to decreased food consumption.

Since the body fluids shift in the upper portion of the body it leads to major CNS system disruption that are in control of the gastric movements which leads to unease and vomiting.

Other body changes include changes in the vestibular receptors of the ears because of the lack of the gravity vector, creates a confused stimuli among the senses which leads to mixed and non coherent reaction to the stimulus.

The main aim of the space nutrition is to provide a meal that is fit for space environment. Usually decreased percentage of fat with increased carbohydrates is used. Decreased fiber content is used in order to avoid constipation. Protein content is similar.

There are number of other factors that play an important role in food intake while in space. On Space Shuttle due to busy schedule the astronauts don't get the time for a regular meal. Space motion and travel sickness may reduce the need to eat, especially in the first few days. Disruptions in biological clock and involuntary rhythms may also alter food intake. There is a changed perception of taste; that is the food that tastes good on the ground may not be as appealing while in space. Monotonous food choices with a limited range may cause "boredom" and decreased food intake.

Vitamin D intake may be significantly reduced in space due to the non availability of UV light activation precursors. Therefore diet is the only source of Vit D. On Earth it is obtained by milk and milk products. But currently there inclusion in space food is very less therefore in order to compensate that loss some non-dairy alternative must be used. On the other hand the use of UV lights can improve Vitamin D content.

From a nutritional viewpoint higher levels of calcium in the diet can cause renal stones or the chances that they will form. On the other hand lower levels of dietary calcium may increase calcium loss. There is not a clear solution at this time.

There is a decreased need for iron in body. The needs for males and females are the same for iron, while they are different here on the ground where females require more. This decreased need for iron results in the less production of blood cells. Consuming too much iron in space could cause toxicity, dizzy and tired behaviour, weight loss and headaches, feeling nauseous and short of breath. With excess of iron in the body, the body is not able to absorb zinc completely. In the long term, the astronaut could develop serious problems including liver damage, arthritis, or heart conditions.

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Likewise, the balance between potassium and sodium becomes fragile in space. These two compounds maintain the body fluid balance, control blood pressure, power cells, and facilitate neural signal transmission. On an average, astronauts tend to consume a large amount of sodium and a little potassium. The high content of sodium is responsible for the disqualification of many foods on earth that would otherwise be suitable for space flights.

At present there are a little changes required in micronutrients because of zero gravity. One likely issue can be that of zinc that is present mainly in muscle and bone. The tissues diminish in mass content therefore leading to decrease in zinc stores. However, this problem has been solved by addition of Iodine to drinking water on Shuttle.

The issues of iodine toxicity would be more expected than deficiency, but to date there are no reported cases of overload. There is no proof that B-vitamin needs are altered in space than on Earth. The danger exists for radiations destroying some of the B-vitamins
One environmental factor apart from microgravity that will be critically changed when in space is radiation. This is especially true for the missions that are there , outside earth`s magnetosphere

Reactive oxygen species will be formed by Ionizing radiation in the body. Lipid peroxidation can be caused by those oxidants and thus alter cellular membranes. Proteins can be made dysfunctional and DNA may have mutations.

The most effectively damaged antioxidants in space are vitamin A and beta carotene, vitamin C (ascorbic acid) and vitamin E (the tocopherols). Several other trace elements are also affected by antioxidant effect these include copper, iron, manganese, selenium and zinc.

4 PACKAGING AND CONSUMPTION

When the Gemini mission was launched by that time the food quality had become appetizing for the Space crew. The astronauts at that time were able to choose from a large variety of different food groups available to them be it sea food, turkey cubes, various vegetable and chicken soups or any dessert.

It is because of freeze drying that the food is able to sustain for a longer period of time without any changes in its flavour. In order to re hydrate that food astronauts simply used a water gun which is used to rehydrate the freeze dried food when water as per instructions is injected into it. Water is added to the re hydratable food bowls and drink pouches through a small hole called a **septum adapter**.

When the Apollo program began (Moon Mission) it was for the first time that hot water was made available to the astronauts which made rehydrating the food products easier. In this mission utensils were used for the first time and the explorers did not have to squeeze the food directly into their mouth now. This introduced a spoon and a bowl in space and a plastic container to carry dehydrated food.

After injecting water into the bowl the opened the sealed and consumed it with spoons. It was because of the wet food that it got stuck to the spoons and did not float away.

Another very important invention that was made during Apollo mission was of using thermo stabilized pouches called **wet packs**. These were plastic and aluminum pouches that kept the food wet and there was no need to rehydrate it. It was because of this discovery the crew members could enjoy cornflakes, beef sandwiches, chocolate pudding and salads.

In 1973, a huge transition in space food led to the development of the **Skylab** that had many similar comforts of a domestic kitchen. A large dining room with a proper table and chair sitting was provided for

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the crew to sit down and eat. This even had a refrigeration facility (which the modern space shuttles don't have) and it allowed storing of almost 72 different varieties of food. it even had the facility to reheat the food using a food warmer tray.

In 1980, the modern space shuttle was launched in which there were all facilities just like those of a domestic and the food had almost become similar to what we eat on earth .The crew had a large variety of food to select from that included 74 different foods and 20 drinks.

The food preparation was done in a galley with water dispenser and a forced air convection oven.

5 RECENT ADVANCES

5.1: Food for MARS: The Mars Mission (starting mid 2030's) in the spacecraft is beyond the moon and needs a complete palatable and safe diet for astronauts. This puts forward a strong challenge in front of NASA scientists who are developing food for mars mission since that mission is going to be for more than five years

Following are the main challenges that are faced by the scientists who are working on the development of space food.

1. The Orion spacecraft has a limited room for supplies and food since the mars mission is for a very long period and the distance to be covered is humungous the astronauts cannot rely on the refuelling of the supplies and food, which would add to the cost of the mission. Therefore they have to carry the entire stock of supplies and food with them at once.
2. The food must be full of variety and choices so that the crew is not bored of it in the course of five year long journey.
3. It must also be noted that the weight of the spacecraft has to maintained, it must not go beyond the calculated value as heavier the spacecraft more fuel does it need for propulsion.
4. The food must stay fresh ,palatable and must have good aroma and taste to make it appetising

5.2: Developing solutions for challenges

In order to reduce the space occupation by foods and other allied items for consumption the scientists are on their way to develop a complete one time intake Ready to Eat bar which will resemble the current protein bars taken to fulfil the protein requirements of the body. Astronauts will eat bars for breakfast, lunch snacks and dinner respectively which will be a mass reduction in the elaborate affair of ReHydratable, thermo stabilised and irradiated foods the astronauts will no longer need the water guns, the spoons and bowls which add to space occupation for consumption of meal.

The other great challenge faced by the scientist is about maintain variety in these food bars, for these are to be consumed for five long years it must be noted that the morale of the crew which will stay there is highly dependent on the food.

The main issue regarding the food bars that arises is its acceptable taste and flavour therefore it passing the test is a great achievement for the food scientists.

The food required for six astronauts is expected to weigh 12 tons –without packaging. Production of these bars will reduce the space occupation and thus reducing the weight of the spacecraft.

5.3: Adding Variety to Longer Missions

The crew members for mars cannot survive on the food bars alone. it is therefore necessary to provide a secondary option to them so that they can enjoy food on board.

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There NASA scientists have developed the space station **Vegetable Production Systems** in which the crew will be able to produce fresh vegetable on board for consumption.

Growing food on space can solve hundreds of different problems at once then the astronauts would not need to stock excess food with them as they can eat fresh and nutritious food on board also adding to the variety that they require or would like to eat.

It was the August of 2016 when the first space grown lettuce was tried by the astronauts on board it was Red Romaine Lettuce which was grown in the artificially created soil nutrient duplicator under the effect of Purple LED lights. The same was brought back to earth to test whether it was it fit for consumption or not.

The scientists are working their way to develop tomatoes, bell peppers and plums along with some staple diet options like wheat on board the main focus is on the food that are rich in vitamins because excessive vitamin breakdown occurs in space.

The other secondary challenges that arise with this development is the extra cost over equipment needed for growing ,harvested and processing of food for example processing of wheat to flour etc. It also involves the risk of devastating crop failure.

5.4 : Keeping the Food Appetizing and Nutritious

The other aspects to be covered are how the senses of smell and taste are changed when in space this is being worked on by making the current astronauts fill survey questioners about their mood before and after eating food, their willingness to cook food onboard and what items do they crave most about when on space

Man is expected to reach mars by mid 2030 and the round trip to mars and back can take two and a half years but NASA is planning to make the consignment of supplies and food reach mars before the Human spacecraft reaches their therefore the food that is to be produced has to remain fresh and consumable for about five long years which indeed is a great challenge.

The scientists are developing ways to maintain the nutritional content in the astronaut's body the excessive exposure to radiations makes few vitamins and other nutrients breakdown automatically and disappear. The most common challenges that are faced in space are that of zero gravity, bone shrinkage and eye squashing and above all the food has to be appetising enough which will thus help the crew to eat it and attain the nutrients required for their survival. Since the astronauts will spend most of their time in space suits in mars it is very difficult to have food in those suits therefore a simple method of food consumption in space suits has been development where the astronauts are simply docked to the crafts and pop out of them to have lunch .it will have a port that will push the straw through to drink liquids and for solids they will already be packed in the space suit s snack bars. The astronauts are expected to stay in these suits for 8 to 10 hours which is long enough for them to feel hungry.

The food that is send to space has often less or lost vitamin content as expected Vit C and Vit A breakdown very easily after processing the scientists don't want to replace the lost vitamins with pills as body does not often respond to the nutrients by pills in the same way as it does to nutrients by food. Giving nutrients by pills can also decrease their urge to have actual food and can create excessive nutrient condition in their body. The only supplement given by pills is of Vit D as no sunlight is available to the crew to produce it in the natural manner that is by the precursor present in food which is (7-dehydrocholesterol.)

5.5: Giving Food Thirty years of shelf Life:

NASA has collaborated with a private company called

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Systems and Materials Research Corporation located in Texas to 3D Print the food which will have a greater shelf life as compare to other food processing methods.

A 3D printer involves the ingredients to be fed in the form of powders and slurries of desired viscosity in the machine cartridges. the cartridges are also filled with desired nutrients and additives that are required to give a better shelf life to the food. This is then extruded from the machine in the desired shape and size using the machine software in which we have to feed the recipe and shape of the product.

The development teams are working on the ways to cook food after printing.

The advancement of the same being printing food on hotplate as they will be cooked simultaneously while printing the only drawback being it needs manual intervention for flipping and stirring. The research is still on in the same

So, for example a printed chicken leg is required, we need to fill the cartridges with protein, lipids vitamins, minerals, additives etc. The most important ingredient need for printing is the binding agent that keeps all these ingredients in desired shape as they are being extruded.

It is worth mentioning it is not only a great breakthrough for space food but also for those old age citizens who are not able to enjoy great variety of food because of the chewy and hard texture. 3D printing creates a smooth food product for them to be relished.

The major Drawbacks include the:

1. Reliability on the printer for food
2. Speed of the printer for mass production
3. Cost of the Printer and allied parts.
4. Food safety.

For the Mars Mission, NASA is trying its best to provide safe and wholesome food to the astronauts so that this dream mission of setting humans on the red planet is successfully accomplished.

6 CONCLUSIONS

The Paper summarizes the methods of processing, packaging (with special focus on recent advances) and consumption of the space food on board.

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