

REVISÃO DE LITERATURA IDENTIFICADO

PRELIMINARY STUDY ON PROBLEMS ENCOUNTERED DURING THE DEVELOPMENT OF NUTRITIONAL STANDARDS FOR THE NASA SPACE PROGRAM (1958–1974)

ESTUDO PRELIMINAR SOBRE OS PROBLEMAS EXISTENTES DURANTE O PERÍODO DE DESENVOLVIMENTO DO PADRÃO NUTRICIONAL VOLTADO AO PROGRAMA ESPACIAL DA NASA NO PERÍODO DE 1958 A 1974

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Eixo Temático 02 - Inovação, Tecnologia, Sustentabilidade e Transformação Global

RESUMO

Introdução: No período entre 1958-1974, a Agência espacial (NASA) apoiou várias frentes de pesquisa, entre estas concentrou-se nos padrões alimentares dos astronautas. O grande desafio era desenvolver um padrão alimentar que produzisse a menor quantidade possível de resíduos e gases, sem comprometer a saúde e sem causar desidratação ou perda significativa de massa corporal. **Objetivo:** Apresentar o processo de desenvolvimento do padrão alimentar utilizado pelos astronautas, o qual permitiu que fossem à Lua e retornassem entre 1958 e 1974, preservando sua saúde, massa corporal e hidratação, além de gerar a menor quantidade possível de resíduos. **Resultados:** Sabe-se que o corpo humano é uma máquina térmica ineficiente, gerador de uma grande quantidade de resíduos líquidos, sólidos e gasosos. Ser capaz de planejar uma dieta para três astronautas do sexo masculino, confinados em um ambiente com volume interno equivalente ao de um Volkswagen Fusca, em uma viagem com duração mínima de 8 dias (Apollo 8) e máxima de 11 dias (Apollo 17), foi o grande desafio. Para isso, foi levada em conta as seguintes condições de contorno: operacional, engenharia e biológica. A consequência deste desenvolvimento foi a publicação dos 72 estudos realizados entre 1960 e 1974. Apesar dos avanços na exploração espacial, astronautas da Apollo perdiam peso por baixa ingestão nutricional. Para garantir o equilíbrio fisiológico, desenvolveram-se sistemas alimentares com alimentos nutritivos, práticos e de sabor familiar, além de embalagens especiais e cardápios adaptados. **Conclusão:** A experiência no desenvolvimento de um protocolo nutricional no programa espacial da NASA, no período entre 1958-1972, demonstrou que os futuros sistemas de alimentação para uso no espaço exigirão esforços para maximizar o potencial desses sistemas em promover o equilíbrio e o bem-estar fisiológico e psicológico de astronautas e suas tripulações. As conquistas do programa de alimentação neste período representaram um ponto de partida significativo.

Palavras-chave: Dieta, Astronautas, NASA, Comportamento Alimentar, Ingestão.

ABSTRACT

Introduction: Between 1958 and 1974, the space agency (NASA) supported various research initiatives, focusing—among other areas—on astronaut dietary patterns. The major challenge was to develop a dietary regimen that produced the least possible amount of waste and gas, without compromising health or causing dehydration or significant loss of body mass. **Aim:** To present the development process of the dietary regimen used by astronauts—enabling them to travel to the Moon and back between 1958 and 1974 while maintaining their health, body mass, and hydration levels, and minimizing waste generation. **Results:** The human body is known to be an inefficient thermal machine that generates large quantities of liquid, solid, and gaseous waste. A significant challenge lay in planning a diet for three male astronauts confined within an internal volume equivalent to that of a Volkswagen Beetle, for missions lasting between 8 days (Apollo 8) and 11 days (Apollo 17). This process took into account operational, engineering, and biological constraints. The outcome of this development was the publication of 72 studies conducted between 1960 and 1974. Despite advances in space exploration, Apollo astronauts experienced weight loss due to low nutritional intake. To ensure physiological balance, food systems were developed featuring nutritious, convenient, and familiar-tasting foods, alongside specialized packaging and tailored menus. **Conclusion:** The experience of developing a nutritional protocol for NASA's space program between 1958 and 1972 demonstrated that future space food systems will require efforts to maximize their potential in promoting the physiological and psychological balance and well-being of astronauts and their crews. The achievements of the food program during this period represented a significant starting point.

Keywords: Diet, Astronauts, NASA, Eating Behavior, Intake.

INTRODUCTION

Physicians and physiologists have long expressed concerns regarding the moment humanity left its natural terrestrial environment to venture into other environments (water, air, and space). There were fears that an astronaut might choke while eating in zero gravity or develop aspiration pneumonia from inhaling food aerosols (particles and droplets). Questions were even raised as to whether an astronaut could digest and absorb nutrients in a zero-gravity environment. Concerns about physiological well-being during weightlessness were compounded by the fear that the strict, unknown limitations imposed by spacecraft design and flight plans might place unacceptable constraints on the food system. Food technologists questioned whether it was possible to produce edible foods capable of withstanding the temperature, pressure, and vibration conditions characteristic of spacecraft.

Despite these initial concerns, limitations, and technological hurdles surrounding the development of space-bound food, adequate and acceptable diets were successfully made available to meet the needs of crew members (astronauts) during flight. In Project Mercury ¹ and the Gemini Program flights ², early food systems resembled military survival rations. For

the first long-duration flight (a two-week mission), Gemini 7 established nutritional criteria that became crucial and began to dictate the work of food system designers. It was necessary to plan for the provision of adequate energy and nutrients within extremely tight mass and volume constraints. The food system limits were approximately 0.77 kg (1.7 lbs) and 1,802 cm³ (110 cubic inches) per person per day. These limits had to accommodate all the packaging materials required to protect the food itself. In Gemini spacecraft, water was a byproduct of fuel cell operation and could be made available for use. This made the solution attractive in terms of food acceptability and weight savings. Consequently, it became possible to use dehydrated foods that could be reconstituted during flight. This served as the starting point for developing the food system for the Apollo missions ^{3 4}. Subsequently, systematic improvements were made as technology became available and its application proved feasible.

This preliminary study aims to outline the development process of the dietary regimen used by U.S. space program (NASA) astronauts between 1958 and 1974, a regimen that enabled them to travel to and from the Moon while maintaining their health, weight, body mass, and hydration levels, all while generating the least amount of waste possible.

METHOD

This study is an integrative literature review employing a documentary assessment and a descriptive approach, conducted to answer the question: how did the improvement of nutritional diets (meal planning) contribute to the success of NASA's space program between 1958 and 1974? The criteria used for the inclusion or exclusion of the researched references were: relevance to NASA and the U.S. space program during the specified period; involvement of technology development for food preservation; coverage of nutritional, medical, and physiological issues affecting astronauts; availability as a free PDF on the World Wide Web; publication in English; and discoverability via Google and Google Scholar. The entire study was conducted between 2024 and 2026.

RESULTS

1. SYSTEMS DEVELOPED

Throughout the various stages of the project that took humans to the Moon (comprising the Mercury, Gemini, and Apollo programs), there was a constant need to develop distinct hermetically sealed environments that would enable spaceflight and extravehicular activities (EVA). Spacecraft and spacesuits provided a microcosm capable of sustaining life during multiple voyages and periods of lunar surface exploration. These small artificial worlds featured the following internal volumes: Mercury, 1.73 m³¹; Gemini, 2.55 m³²; and Apollo, 6.2 m³⁴. Such environments housed crews of one to three people and required a suitable atmosphere, supplies of food and water, waste disposal methods, and techniques for continuously monitoring the astronauts' condition. The development of these spacecraft systems constituted a significant part of NASA's Biomedical Program³.

2. THE APOLLO FOOD SYSTEM

The development program for the Apollo food system provided an adequate and safe nutritional standard for the longest phase of space exploration to date. This was achieved by taking into account critical biological, operational, and engineering constraints. These constraints were identified and classified, and are listed in FIGURE 1. Details regarding these constraints are described in Apollo³.

Operational	Engineering	Biological
Vehicle interface	Weight	Safety
Stability	Volume water or rehydration	Nutrition
Packaging		Organoleptics
Storage	Pressure	Personal hygiene
Preparation	Temperature	Ingestion
Servicing	Relative humidity	Digestion
Waste disposal	Acceleration	Absorption
Schedules	Vibration	Gastroenterology
Crew time	Power	Crew idiosyncracies

FIGURE 1: Boundary Conditions for the Development of the Apollo Food System (from author)

All technological development regarding the food system created for the Apollo project evolved over the years, supported by the "US Air Force Manned Orbiting Laboratory

Program, US Army Natick Laboratories, industry, and universities." The initial food formulations, termed "space foods", were designed to be bite-sized, suitable for finger consumption, and puree-like in consistency, or capable of being squeezed directly into the mouth from flexible metal tubes (similar to toothpaste tubes). Both the food products and their packaging underwent modifications throughout the Mercury ¹, Gemini ², and Apollo ⁴ projects.

These modifications to the food system were particularly necessary during the Apollo Program for the following reasons:

1. The food supply on board proved insufficient to maintain nutritional balance and body weight;
2. Symptoms of nausea, anorexia, and undesirable physiological responses exhibited by some crew members were partially attributed to the food consumed;
3. Excessive time and effort were spent on meal preparation and consumption;
4. The water used to reconstitute freeze-dried foods was unpleasant, as it contained high levels of dissolved gases;
5. Functional failures (ruptures) occurred in the packaging of rehydratable foods during the early Apollo flights.

Continuous changes in food system technology improved the system's nutrient delivery capabilities, aiming to enhance acceptance and ease of use. This general trend of increasing acceptance was observed as the Apollo flights progressed.

A general overview of the evolution of food systems can be gained by comparing the flight menus from the Apollo 7, 11, and 17 missions (FIGURE 2). While menus were very similar for each astronaut on the Apollo 7 mission, a high degree of individualization was observed on Apollo 17. This difference reflected the astronauts' greater freedom of personal food choice as the program evolved. The FIGURE 2 presents the variety and diversity of foods available to the Apollo 17 crew.

Day 1	Day 2	Day 3	Day 4
Meal A			
Peaches (R)	Applesauce (R)	Fruit cocktail (R)	Ham and applesauce (R)
Bacon squares (IMB)	Sausage patties (R)	Bacon squares (IMB)	Peanut cubes (DB)
Cinnamon bread cubes (DB)	Apricot cereal cubes (DB)	Cinnamon bread cubes (DB)	Strawberry cereal cubes (DB)
Breakfast drink (R)	Breakfast drink (R)	Breakfastdrink (R)	Breakfast drink (R)

Legend

R: Rehydratable

IMB: Intermediate moisture bite

DB: Dry bite

FIGURE 2: Typical menu developed for Apollo missions 11 through 17 (adapted ³)

This increase in food variety was important, but the improvement in the quality of individual items was even more significant. This improvement was not evident solely from the list of foods (for example, the fruit salad was reformulated because the original product was crushed by the effects of atmospheric pressure on the packaging and was difficult to rehydrate).

The evolution of space food science and technology can be tracked through the number of bibliographic references produced (FIGURE 3).

1960: [6] [7] [8] [9]
1961: [10]
1963: [11] [12] [13] [14] [15]
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1971: [57] [58] [59] [60] [61] [62]
1972: [63] [64] [65] [66]
1973: [67] [68] [69] [70] [71] [72] [73] [74] [75]
1974: [76]

FIGURE 3: Number of studies published between 1958 and 1974 regarding space food science and technology (from author).

As each Apollo mission flight had different objectives, the scope of the Apollo food system was modified to meet the specific needs of each flight. The main flight phases (regarding food provision) included the times the crew occupied the Command Module (CM) and the Lunar Module (LM), as well as transport in various vehicles from the recovery site to NASA's Lyndon B. Johnson Space Center in Houston, Texas. It was also necessary to develop a contingency (emergency) power system for use in the event of vehicle depressurization. For Apollo flights 11 through 14, a mandatory post-flight quarantine period was established. This required a power system for use in the Mobile Quarantine Facility (MQF) and the Lunar Receiving Laboratory (LRL). Each of these environments presented a different set of boundary conditions for the food system. Metabolic balance studies were also conducted during the Apollo 16 and 17 missions. These studies imposed specific requirements on the food system regarding pre-flight, in-flight, and post-flight measurements, as well as the control of food intake.

It is also important to note that, prior to the Apollo launch, each crew member (prime and backup) evaluated the available flight foods and selected their preferences. These foods were then organized into nutritionally balanced menus (reviewed by both the crew and nutritionists) to ensure maximum acceptability within nutritional constraints. Finally, the astronauts were instructed on the storage, preparation, and disposal of waste generated within the spacecraft.

The food system developed for in-flight consumption during Apollo missions consisted of two basic food groups:

1. lightweight, long-shelf-life dehydrated foods requiring rehydration before consumption;
2. ready-to-eat dehydrated foods.

Dehydrated foods were selected due to their shelf life and because mass was a critical factor for the Apollo spacecraft. Since water accounts for approximately 80% of the mass of fresh food, removing this component resulted in a reduction of the food system's mass. It is worth noting that the water required for rehydration was available as a byproduct of fuel cell operations (in which hydrogen combines with oxygen to generate electrical energy).

3. FOOD PORTION SIZING

Defining the ready-to-eat portion size for foods provided during spaceflights is a crucial factor when considering the constraints of limited space. It was decided that these portions would be reduced in size and serve as a complement to rehydratable foods during the

Apollo program's first crewed flight (Apollo 7). These foods were "bite-sized" and offered in the following forms:

1. dehydrated (moisture content below 2%) or prepared to retain the product's water (rendering it unavailable for microbial growth);
2. intermediate-moisture (falling between fresh foods at one end of the spectrum and dry foods at the other); those with moisture content below 40% were highly accepted, as they closely resembled the texture of fresh foods and were ready to eat without the need for rehydration.

Even with this combination of foods, the variety of textures and flavors was limited during the early Apollo flights. This situation was gradually rectified as the program progressed 3.

4. PACKAGING DEVELOPMENT

Packaging, like the food itself, underwent modifications throughout the Mercury, Gemini, and Apollo programs. Flexible packaging was developed to protect individual food portions and facilitate handling and consumption. After several rounds of design engineering cycles, the resulting packaging for rehydratable foods featured the following characteristics:

1. an improved transparent barrier film, consisting of a polyethylene-fluorohalocarbon-polyester-polyethylene laminate;
2. a water injection point featuring a spring-loaded, one-way valve;
3. an improved opening that allowed the food to be consumed in weightless conditions using a standard tablespoon. Cold water [approximately 283 K or 10°C] and hot water [approximately 333 K or 60°C] were available on the spacecraft for food preparation. After injecting water using the Apollo dispenser, the package had to be squeezed to rehydrate the food, allowing it to be opened for consumption. The initial packages (Figure 4) were equipped with plastic tubes through which the rehydrated food was squeezed directly into the mouth. This configuration was changed with the introduction of a bowl-shaped package (Figure 5) designed for use with a spoon.



Figure 4: Packaging for rehydratable foods available on Apollo missions ³.



Figure 5: Spoon-bowl type packaging for rehydratable foods available on Apollo missions, shown opened with the spoon inserted ³.

Ready-to-eat foods in small portions were packaged in containers made of laminated plastic (the same material used for rehydratable food packages). These packages could be opened simply by cutting them with scissors (Figure 6), and the food was consumed directly from the package or by hand.

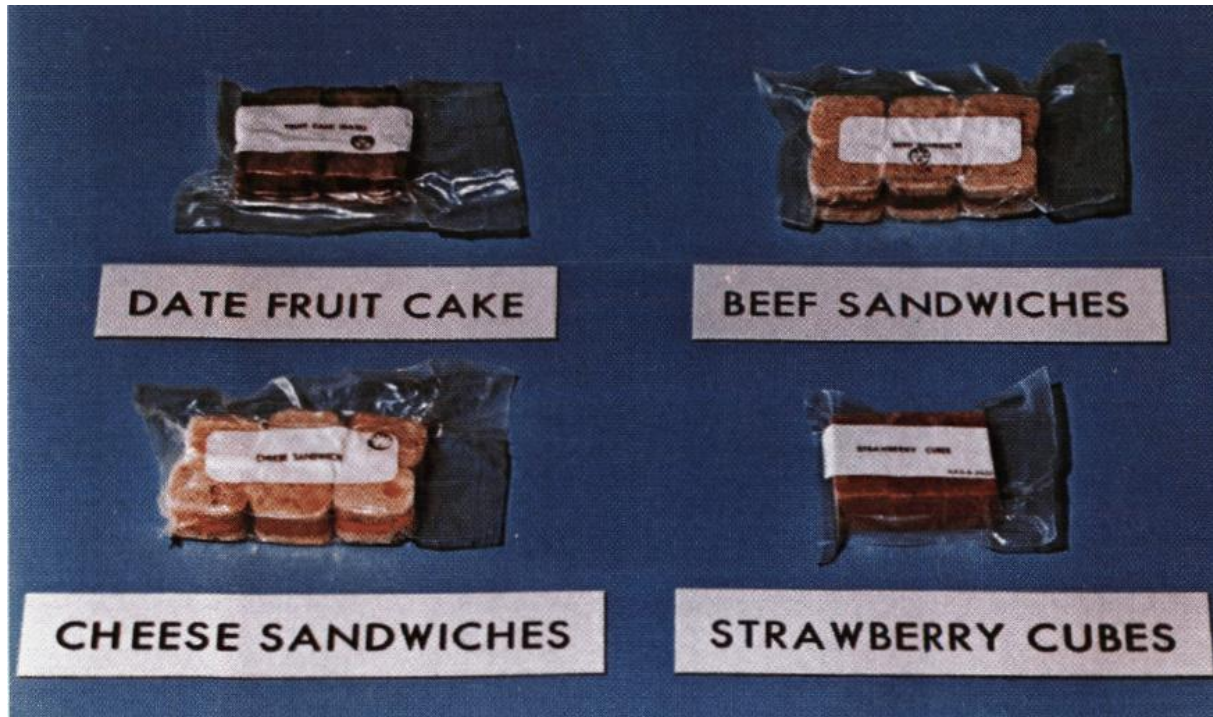


Figure 6: Examples of packaging options available on Apollo flights [1]: small, ready-to-eat, intermediate-moisture, and dry foods ³.

CONCLUSION

Improvements and advancements in space food systems were achieved during the Mercury, Gemini, and Apollo programs. Nevertheless, with few exceptions, Apollo astronauts did not consume sufficient nutrients, resulting in a loss of weight, fluids, and electrolytes—a common occurrence. The Apollo project's food program demonstrated that human eating habits do not change easily and that adequate nutrition begins with appropriate foods presented to the consumer in a familiar manner.

A food system designed for space use must meet program constraints and provide adequate nutrition to maintain physiological balance amidst mission-specific stresses. Such a system must rely on nutritious, easy-to-prepare foods with familiar flavors and textures that offer enjoyment, relaxation, safety, and satiety.

Modifications to the Apollo food system aimed to improve astronaut nutrition. Individual food items and in-flight menus were altered as nutritional countermeasures against weight loss. Unique food items were developed, seeking a balance of nutrition, high acceptability, and the convenience of ready-to-eat, long-shelf-life products. Specialized food packaging was also developed.

Space program experience has shown that future space food systems will require efforts to maximize their potential in supporting physiological and psychological balance, as well as the well-being of astronauts and crews. The achievements of the Apollo food program represent a significant starting point.

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