SPACE AQUACULTURE

A Sustainable Pathway for Next Generation Food Systems for Astronauts

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EDITION: VOLUME 02, ISSUE 02 , - FEBRUARY 2026

ISSN 3107-9903

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Abstract

Space aquaculture is the cultivation of aquatic organisms in space under controlled conditions. Food energy requirements for humans during spaceflight and residing in space are similar to those on Earth. Astronauts experience physiological challenges in microgravity. If human energy intake decreases in space, it may lead to a 30% reduction in protein synthesis, and certain body problems may occur, including cardiovascular deconditioning, bone demineralization, muscle atrophy, and immune system deficiency. There is a need for a fresh animal-based food source to be included in the diet of space residents. Aquatic organisms have higher nutritional value than other food sources, making them an ideal food source for the human community who are there on the moon or Mars for long-term residence in space. Culturing aquatic organisms requires water, oxygen, and hydrogen, resources that may be available in extraterrestrial environments (Mars, Venus, the Moon). The use of innovative technologies, such as Recirculating Aquaculture Systems (RAS) and Integrated Multitrophic Aquaculture (IMTA), will be a valuable approach for culturing fish in space. However, culturing them in a constrained environment, such as microgravity, is difficult due to water management, waste recycling, and system stability. The successful Lunar Hatch program was conducted in France to assess the feasibility of space aquaculture through Earth-based space simulations. This article explores the potential of space aquaculture for sustainable food production to support astronaut nutrition.

Keywords: Space aquaculture, BLSS, astronauts, food security, astronaut nutrition

Introduction

The supply of energy and oxygen, and the recycling of biological waste, are considered major concerns for long-term manned stays outside the planet. The freeze-dried foods are currently used to meet human nutritional needs in space. However, freeze-dried foods, when stored for more than a year, may become unstable, leading to degradation of essential nutrients such as potassium, calcium, and vitamins, which are important for maintaining muscle and bone in altered gravity (Cooper et al., 2017). The production of plants, vegetables, and microalgae in altered gravity was studied, and space aquaculture was considered to meet the nutritional requirements of space residents. The International Space Station reports that the availability of fresh food (including farmed aquatic species) may have positive physiological effects on residents in space (Douglas et al., 2020). To achieve this, several research studies have been conducted, and the results indicate that fish embryos are more resistant to neutrons and gravity. Additionally, the growth period of fish in the space until it reaches an edible size has been studied. The recirculating aquaculture system was found to be superior for fish growth in such an environment (Przybyla, 2021).

Figure 1. First aquaculture farms in Mars (Source: https://matkuling.com/news/first-aquaculture-farms-mars-space/)

Need to culture fish in space

Fish, being an excellent source of protein, omega-3s, and vitamin B, is needed for the maintenance of muscle mass for astronauts. Further, keeping aquariums has also been demonstrated to lower heart rate and relieve psychological stress, which may have positive emotional effects on crew members. In addition, culturing fish in space is comparatively easier than farming other animals, such as poultry or cattle, because livestock require a large area for rearing, which would be a competing factor. Moreover, fish require less energy and oxygen (compared to mammals) and generate less carbon dioxide, which is an important factor for the survival of astronauts in space. Another important factor to consider is waste management. Compared to fish, other animals, such as pigs, chickens, cows, or goats, produce large amounts of waste that is very difficult to remove from the system. On the other hand, the waste excreted by the fish can be easily removed from the system. Another advantage of culturing fish in space is that they can experience gravity, as they possess a swim bladder and otoliths that help maintain buoyancy. So, it is very clear that the altered gravity will not be a disturbance factor for the swimming activity of fish.

Nutritional requirements of astronauts

For proper bone maintenance, cardiovascular function, iron metabolism, and muscle function, astronauts need specific nutrients. Balanced nutrients, such as carbohydrates, fats, proteins, and minerals, must be maintained. The composition of nutrients, or the proportions of the food, varies depending on the duration of stay and individual needs. The most important nutrients for bone health are calcium, vitamin D, and iron. Nowadays, technologies such as freeze drying and thermos stabilization are used to retain the flavor, texture, and nutritional composition of food.

Feasibility (Fish embryos to Moon)

Water in the celestial bodies is saline or hypersaline. Based on this, species selection for space culture depends on the fish's physiology, behaviour, and euryhaline nature. For the culture, fish embryos need to be sent to space for hatching. The Lunar Hatch program (2019) is investigating the shipping of fish eggs to space for hatching in a lunar bioregenerative life support system (BLSS).). Rearing adults for reproduction will not be possible in the space. So, Eggs, as the biological stage for space travel are relevant mainly because of the low volume of water required for egg incubation (<1 kg

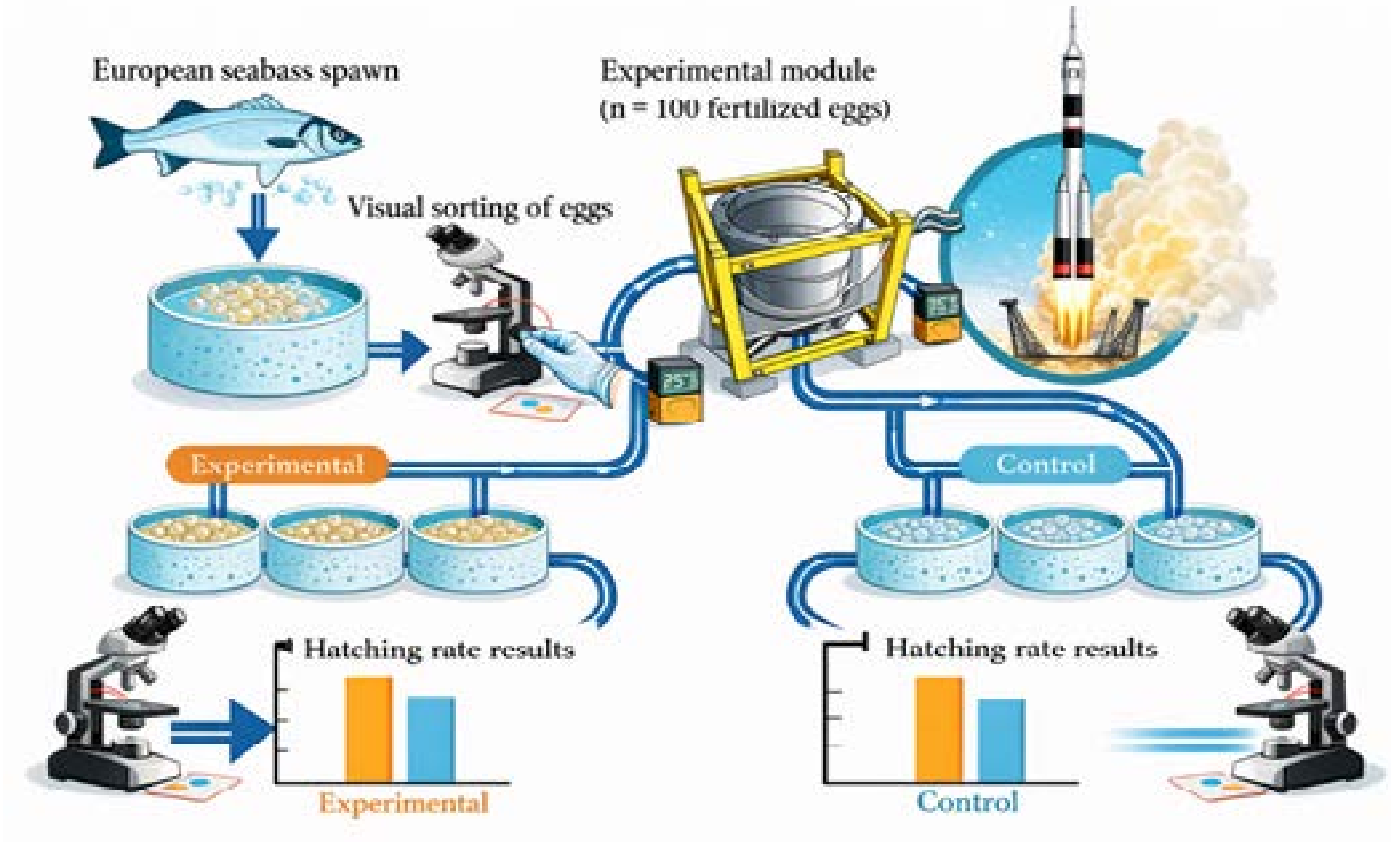

Figure 2. Protocol for Vibrations test on European seabass embryos (modified with Przybyla, 2021)

for about 900 future larvae). Fish eggs can be transported using an automated cargo ship. Culture in the land-based system will not have a serious impact on fish embryos, but when embryos are carried in space, they will be affected by higher acoustic levels, mechanical vibrations, hypergravity, micrograyity, and radiation from the motors, as well as atmospheric acceleration. Experiments on simulated acoustic and mechanical vibrations (Fig. 2), hypergravity, microgravity, and radiation were conducted on European seabass embryos. Hatching rate and survival have no significant differences, with the control indicating that survival and hatchability of an aquaculture species will be the same on the Moon or Mars after space travel (Przybyla, 2021)

IMTA (Integrated Multitrophic Aquaculture) for feeding fish in Space

Farming fish in space requires feed to raise them, but it is not possible to send feed from Earth to the Moon or Mars. The aquatic organisms' food web is a complex cycle that starts with phytoplankton and ends with the conversion of fish biomass. Each species in the aquatic system has diverse feeding habits. So, IMTA could become an innovative method for aquatic system has diverse feeding habits. So, IMTA could become an innovative method for feeding fish on the Moon or Mars. Fish waste, or sourced from other sources such as byproducts from space agriculture or food waste released by astronauts, which acts as fertilizer, can act as a food source for aquatic organisms (from algae to invertebrates). The N/P ratio from fish waste fits the requirements of algae for invertebrates. Fish, feeds containing zooplankton grown (utilizing algae) in the IMTA system or microalgae (mostly marine) have been tested successfully, with no alteration in growth or organoleptic quality, in a fish feed containing 20–40% microalgae (Stuart et al., 2021). Molluscs and algae can also improve water quality, thereby increasing fish growth rates. From Figure 3, it is clearly evident that FCR for fish is very low when compared with other terrestrial animals. So, culturing fish in space will not be difficult to feed astronauts (Przybyla, 2021).

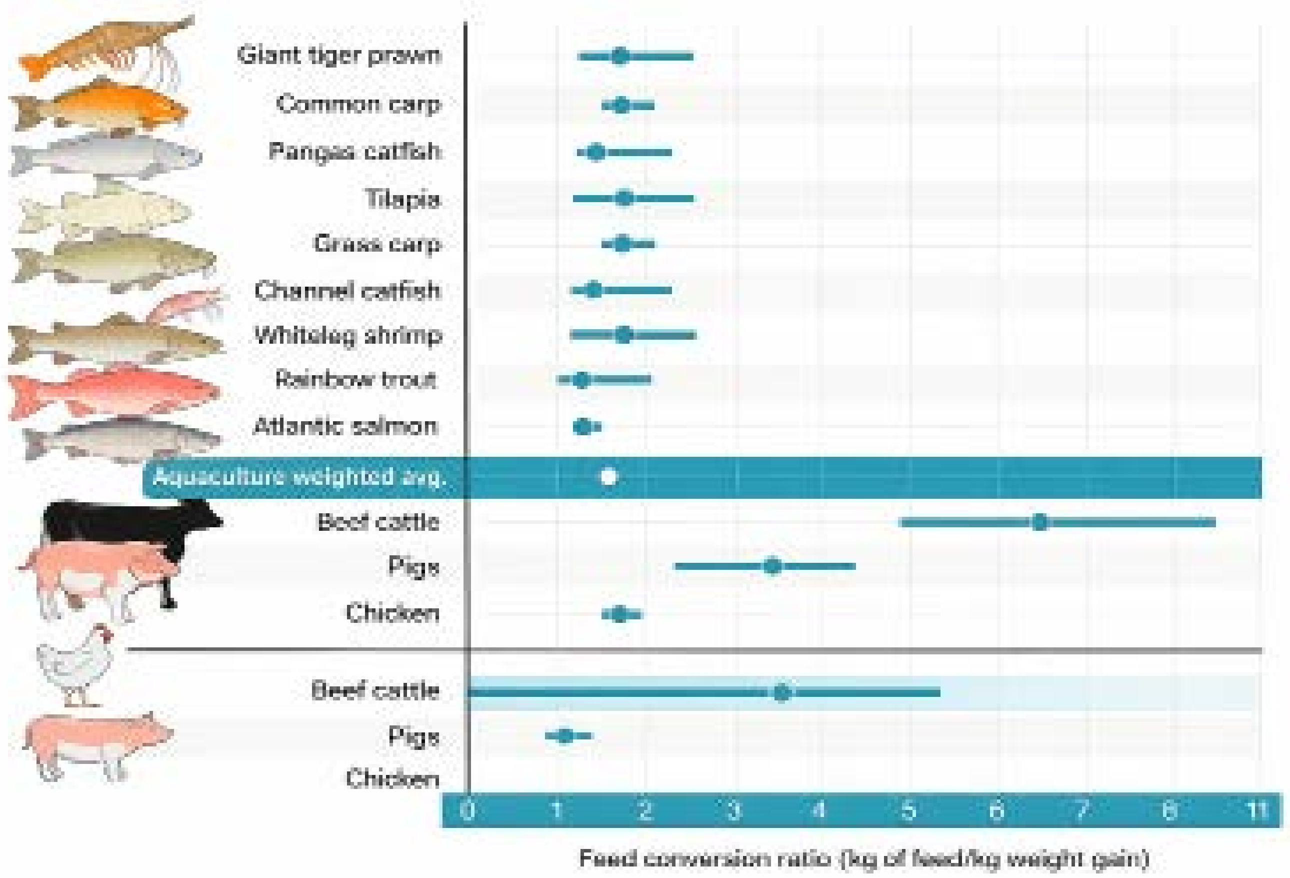

Figure 3. FCR for selected aquaculture species compared to terrestrial farmed species (Fry et al., 2018)

Limitations and future prospects

Various parameters need to be considered before designing the aquaculture system for space, including the number of astronauts/residents to feed, water availability, energy requirements, and the mission duration. The culture system requires water circulation, but this must be determined based on lunar gravity. For a week, a single person requires 250 g of fish to meet the recommended nutritional requirements. The thermal growth coefficient of the selected fish needs to be considered, as there will be 14 days of sunlight and 14 days of darkness in the space context. This will affect fish growth in BLSS. Depends on photosynthesis by algae, hydroxyl extraction, and oxygen from the regolith, which can be adjusted to meet the fish's biological demands (DO). Algal biomass extraction is a challenging process in space due to limited space. Extraction needs to be performed periodically to prevent water degradation and excessive O2 consumption.

Conclusion

Space aquaculture will become a valuable food source for humans undertaking long-term space missions. Space aquaculture is nearing reality, but it depends on in situ water and energy availability. The nutrients in fish can provide valuable health benefits to humans, particularly in preventing cancer caused by long-term radiation exposure in space. An additional simulation experiment is needed on Earth to study interactions between organisms and gas flow management. Everything is based on research done on Earth using space simulations. However, a properly designed, scientifically grounded, manned space-based mission to culture fish in space is needed in the future to increase sustainability and meet the food requirements of humans and astronauts.

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