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Space for food and food for space: A dual perspective on innovation, sustainability, and business

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Abstract

The relationship between the space economy and food is becoming increasingly important in both scientific and economic terms. On the one hand, the challenge of "food for space" concerns how to provide humans outside the terrestrial atmosphere with safe, nutritious food in a sustainable manner during short and long-duration missions, including potential future lunar and Martian (or other planets) habitats. On the other hand, "space for food" refers to the use of space-based technologies, especially satellite Earth observation and data, to improve agricultural productivity, climate resilience, and food security on our planet. This paper argues that these two directions are not separate domains but a dual system. Space food research develops closed-loop, resource-efficient systems that can spill over into terrestrial agriculture, while satellite data and digital agriculture tools developed for Earth support more resilient food systems and generate new business opportunities. Drawing on official sources from NASA, ESA, FAO, the UN, and selected company and business cases, the paper shows that the convergence of New Space, AgTech, and AI is creating a new frontier for sustainability and business model innovation (Loureiro & Palmer, 2026). The paper contributes by interpreting "food for space" and "space for food" as a dual innovation system in which AI could act as a connective layer: it transforms satellite observation, plant-growth experiments, closed-loop food production, and agrifood business models into actionable decisions that can improve mission autonomy, food security, climate resilience, and sustainable business development.

Keywords: space economy, food systems, new space, agrifoodtech, innovation

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Generative AI tools (primarily Claude and ChatGPT) were used to support preliminary research activities, language editing, proofreading, and text refinement. The ideas, conceptual development, analysis, interpretation of evidence, and conclusions presented in this paper are entirely those of the authors, who assume full responsibility for the content. All outputs generated with AI assistance were critically reviewed and validated by the authors. A record of the prompts used during the preparation of the manuscript has been retained.

Space for food and food for space: A dual perspective on innovation, sustainability, and business

Introduction

The space economy has moved far beyond its original identity as a government-led domain for exploration, defence, and scientific prestige. Today, it is a diversified economic ecosystem that includes launch services, satellites, communications, Earth observation, navigation, advanced manufacturing, and downstream data applications. Some studies call this phase the "New Space Economy", although it is difficult to find a universally accepted definition. At the same time, it is evolving rapidly, and new characteristics emerge continuously in this sector. Estimates of its size vary because organisations define the boundaries of the sector differently. The Space Foundation estimated the global space economy at $570 billion in 2023, while McKinsey, using a broader definition that includes "reach" applications enabled by space technologies across the wider economy, estimated that figure at $630 billion in 2023 and projected it would reach $1.8 trillion by 2035 (World Economic Forum, 2024). The OECD, meanwhile, emphasises that better statistical methods are needed to understand the sector's real contribution and policy implications (OECD, 2022).

Food systems are equally central to today's global economy and society. They underpin health, employment, trade, and environmental sustainability, but they are also under acute strain. The UN notes that food systems account for more than a third of human-caused greenhouse gas emissions, and that changes in production, consumption, transport, and waste management are essential to climate mitigation. FAO similarly stresses that digital technologies and AI can transform agrifood systems by improving precision farming, climate-smart agriculture, market access, and supply chain efficiency. In other words, food is not only an object of consumption; it is a strategic sector that lies at the intersection of climate, development, and innovation policy.

The intersection of these two domains, agrifood and AI, produces a particularly rich research field. Building on the traditional classification of "upstream" (development on earth and deployment of space assets — this activity is mainly referred to as "Earth to space") and "downstream" (which include services and applications derived from space assets and their data for use on the Earth — it is also usually called "space for Earth") activities, we can approach the intersection of space economy and food systems with two different perspectives. "Food for space" asks how to feed humans in space contexts (from life on the International Space Station to future life on the Moon or other planets), environments where every gram, watt, and liter matters, while "space for food" asks how space technologies and space data can impact the production of food on Earth, to make agriculture (and related activities) more productive, resilient, and sustainable. The following research question guides this article: How can the reciprocal relationship between "food for space" and "space for food" generate innovation, sustainability benefits, and new business opportunities across space and agrifood systems? We argue that the answer lies in treating the two flows as one dual innovation system. Technologies designed for space habitats can generate terrestrial spillovers for controlled-environment agriculture, resource efficiency, and resilient food production.

In contrast, satellite data, digital agriculture, and AI developed for Earth can support future autonomous food systems beyond Earth. The paper moves beyond a descriptive mapping of cases. It proposes an impact-oriented framework for understanding how science, business, and policy can use the food-space nexus to address strategic challenges on Earth and in space.

Food for space: feeding humans beyond Earth

The history of space food reflects the broader evolution of human spaceflight, illustrating how technological innovation has progressively addressed the nutritional, operational, and psychological challenges of living beyond Earth.

Soviet cosmonaut Yuri Gagarin ate the first meal ever consumed in space during the historic Vostok 1 mission in 1961. His food consisted of a meat puree packaged in a tube similar to a toothpaste container, accompanied by a chocolate sauce stored in a second tube. In the same year, American astronaut Alan Shepard, before his suborbital Mercury-Redstone 3 (Freedom 7) mission, consumed a traditional meal of steak and eggs. This choice was not accidental: the meal was low in fiber. It produced minimal digestive residue, reflecting early concerns not only about nutrition in space but also about digestion and waste management in microgravity.

During the Gemini and Apollo programs of the 1960s, NASA developed increasingly sophisticated food systems. One notable example was the so-called "sandwich cubes," small cubes of baked bread coated with a layer of fat to prevent the release of crumbs. In the confined environment of a spacecraft, even a single floating crumb could interfere with sensitive equipment, contaminate air filtration systems, or pose risks to astronauts.

A unique historical episode occurred during the Apollo 11 mission in 1969, when Buzz Aldrin became the first person to consume alcohol in space. As part of a private Christian communion ceremony, he consumed a small amount of wine together with a consecrated wafer before stepping onto the lunar surface. Although symbolic and religious in nature, the event remains a singular milestone in the history of space food consumption.

NASA later explored the possibility of including alcoholic beverages aboard Skylab, the first American space station, occupied between 1973 and 1974. Researchers consulted oenologists from the University of California, who suggested sherry due to its relative stability over time. Because glass bottles were obviously unsuitable for spaceflight, a sherry-based cream was packaged in plastic pouches placed inside pudding-like containers. While the product performed satisfactorily during technical tests, its strong odour and negative reactions from the media and public opinion regarding alcohol consumption by astronauts ultimately led NASA to abandon the initiative.

The private sector also showed considerable interest in the emerging field of space food. In the early 1980s, The Coca-Cola Company reportedly invested approximately $500,000 in developing a beverage dispenser suitable for microgravity conditions. However, carbonated and sparkling drinks proved extremely difficult to manage in space because the absence of gravity prevents gases from separating naturally from liquids, making both storage and consumption extremely problematic.

Similarly, Whirlpool Corporation developed a freeze-dried ice cream for the mission Apollo 7 in 1968. The experiment was not considered particularly successful in orbit, largely because of the product's poor texture and sensory qualities under spaceflight conditions.

In 2014, Lavazza and Argotec in Turin (Italy) created the first capsule espresso coffee machine for the International Space Station (ISS)[1]. On May 3rd, 2015, Samantha Cristoforetti became the first person to taste an Italian espresso coffee in space, during the Futura Mission. This special machine, called "ISSpresso", was the result of a long and difficult research process, which culminated in the development of a special zero-gravity extraction system. "Coffee for Space" therefore became not only a simple moment of pleasure and indulgence, but the result of intense scientific research, experimentation, and prototypes, focused on the behaviour of fluids under conditions of high pressure and microgravity. In terms of functionality, ISSpresso provided three dispensing options: espresso coffee (30 ml), long coffee (60 ml), and hot beverages, including tea or broth (120 ml). The machine, measuring 43 cm × 36 cm × 42 cm and weighing nearly 30 kg, also incorporated a 60 ml cleaning cycle designed to flush and sanitise the hydraulic system after each beverage preparation. The broth-dispensing capability further enabled the rehydration of dehydrated space food, thereby supporting meal preparation aboard the International Space Station. The machine was used in conjunction with a special transparent zero-gravity espresso cup that uses capillary action to wick fluid into the mouth.

Figure 1 - Astronaut Samantha Cristoforetti on the ISS, next to the ISSpresso machine.

(Source: NASA - https://www.flickr.com/photos/nasa2explore/17381322102/
Public Domain, https://commons.wikimedia.org/w/index.php?curid=40003234)

[1] Developed for the International Space Station by Argotec and Lavazza through a public-private partnership with the Italian Space Agency (ASI).

Over time, the quality, variety, and safety of space food improved dramatically. Modern space meals are designed to remain stable for extended periods, often several years, while preserving nutritional value and sensory appeal. Foods such as nuts, dried fruits, and chocolate undergo rigorous safety procedures, including irradiation and specialised packaging. Many meals are either freeze-dried or thermostabilized, processes that eliminate microbial contamination at high temperatures and extend shelf life while minimising weight and storage requirements.

A notable example of commercial involvement occurred in 2001, when Pizza Hut partnered with the Russian space program to deliver a pizza to the International Space Station (ISS). Russian cosmonaut Yuri Usachov consumed a salami pizza in orbit, making it the first pizza ever eaten in space. To compensate for the reduced sense of smell and taste commonly experienced by astronauts due to fluid shifts in microgravity, the pizza recipe contained significantly higher amounts of salt and spices than a conventional terrestrial pizza.

Today, food aboard the International Space Station is far more diverse and personalised than in the early decades of space exploration. Astronauts can choose from hundreds of menu items and, in some cases, collaborate with chefs from their home countries to develop customised meals. Italian astronaut Luca Parmitano, for example, enjoyed specially prepared lasagna, caponata, and tiramisu during his missions. Similarly, Samantha Cristoforetti requested a monkfish dish with saffron sauce and broccoli for her Minerva mission. Preparing such meals presented significant technological challenges, as thermostabilization — typically requiring temperatures above 120°C to eliminate microbial contamination — can negatively affect texture, making ingredients such as fish and vegetables excessively soft or rubbery.

The evolution of space food thus illustrates a broader shift in the philosophy of human spaceflight. Food is no longer viewed merely as a source of calories but increasingly as a critical component of astronaut health, psychological well-being, cultural identity, and mission success. As humanity prepares for long-duration missions to the Moon and Mars, the development of advanced food systems is expected to become one of the central pillars of sustainable space exploration.

Feeding astronauts is a much more complex task than simply sending packaged meals into orbit. NASA's food systems team explains that space food must be nutritious, appetising, safe, compact, easy to prepare, and compatible with microgravity constraints; it also has a social and psychological role because meals help sustain morale and routine during long missions. NASA's food systems laboratory produces freeze-dried food and heat-stabilised foods, and it is already developing food concepts for missions beyond low Earth orbit, where supplies may need to remain in acceptable condition for up to five years.

Microgravity alters the human body in ways that matter directly for food and nutrition. NASA notes that, without proper diet and exercise, astronauts lose muscle mass faster in microgravity, and body fluids shift upward toward the head, which can affect vision and other physiological processes. These changes matter because long-duration missions require food not only as fuel, but as a countermeasure supporting health, cognition, and performance. The challenge becomes more difficult as mission duration increases, especially for planned exploration missions to the Moon and Mars.

Because prepackaged food alone is not sufficient very long missions, the field has moved toward controlled-environment cultivation and regenerative systems. NASA's Veggie plant-growth system illustrates this transition. Veggie is a "space garden" on the International Space Station, roughly the size of a carry-on suitcase, typically holding six plants. It uses growth pillows, clay-based media, and LED lighting to support plant growth in microgravity, while also adding fresh food to the astronauts' diet thus improving well-being. NASA reports that researchers have successfully grown lettuces, mustard greens, kale, tomatoes, radishes, peppers, and other crops in space experiments.

A major scientific reason for this shift is that plant growth in space is not a simple extension of terrestrial agriculture. Recent systems-level research on space agriculture reinforces this point. Fazayeli et al. (2025) describe space agriculture as an integrated challenge involving environmental stressors, resource limitations, biological adaptation, and operational constraints. Their review highlights that food production beyond Earth must address reduced gravity, radiation exposure, limited water and nutrient availability, regolith-based substrates, altered plant physiology, constrained crew time, and the need for closed-loop systems. This perspective strengthens the argument that future "food for space" systems cannot be designed as simple extensions of terrestrial agriculture. Rather, they require the integration of controlled-environment agriculture, bioregenerative life-support systems, crop selection, hydroponics, genetic engineering, robotics, sensors, and artificial intelligence. In this sense, space agriculture represents both a life-support technology for long-duration missions and a platform for innovation with potential spillovers for terrestrial food security in extreme or resource-limited environments. Research published in *npj Microgravity* and *Nature Communications* shows that altered gravity and radiation can modify gene expression, cell differentiation, signalling, and physiological development in plants, and that long-duration human missions will require more effective plant-based food production and resource regeneration. A 2021 Nature Communications paper argues that ideal space crops should deliver more edible biomass, higher nutrient density, and better efficiency from fewer inputs, because existing crops are not yet sufficiently productive for space farming at scale.

The most mature systems in this area are integrated life-support architectures. ESA's MELiSSA project, for example, is a closed-loop life-support concept managed by ESA and built around microbial bioreactors, wet oxidation, filtration, and higher plant chambers. ESA describes the long-term goal as a closed ecological system with close to 100% efficiency, reducing or eliminating the need for resupply. The MELiSSA network is highly international, involving more than 40 parties from 13 countries and multiple spin-off companies. This makes MELiSSA valuable not only as an exploration project but also as a model of distributed innovation across academia, industry, and public agencies (ESA, 2009).

A second important analogue is EDEN ISS, led by the German Aerospace Center (DLR). DLR reports[2] that the Antarctic greenhouse produced around 106 kilograms of edible biomass by late November 2019, providing fresh produce to the winter crew and simulating the conditions of a future space greenhouse. The Antarctic setting is the closest replica of microgravity, with a realistic stress test for closed, remote, and resource-constrained food production systems. As a result, EDEN ISS is often treated as a bridge between space agriculture and controlled-environment agriculture on Earth.

The technological frontier is moving toward even more ambitious systems. NASA's Deep Space Food Challenge, launched with the Canadian Space Agency, seeks innovative food systems that can support Mars-class missions and other long-duration exploration

[2] https://www.dlr.de/en/irs/research-transfer/missions-and-projects/eden-iss

scenarios. NASA describes the challenge as focused on hearty, tasty, and sustainable food systems that meet the logistical constraints of deep space. This is important because it signals that space food is becoming an innovation market rather than only an engineering problem. It creates room for startups, food-tech firms, and bioengineering ventures to compete on performance, shelf life, resource efficiency, and taste.

One of the most visible commercial cases is cultivated meat. ESA reported in 2023 that it had supported two research teams to examine the feasibility of cultivating meat in space, as a protein source that could be produced in situ. ESA framed this work as relevant both for long-term mission autonomy and for psychological support of crews, because familiar fresh food can matter as much as calories in isolated environments. In parallel, Aleph Farms officially reported that it had produced the first cultivated meat in space in 2019 with 3D Bioprinting Solutions on the ISS. They later conducted an ISS experiment in 2022 to study cell growth and maturation in reduced gravity. These are company-reported cases, but they are public, documented, and highly relevant to the field.

More recently, Redwire announced[3] in June 2026 that it had been awarded a contract by Astrobiome Space to launch an inaugural space agriculture mission in what it described as the world's first commercial space greenhouse. The mission aims to grow strawberries on the ISS and to test a proprietary soil enhancement product, while also supporting future research on fungi and other crops. This is an important signal of market maturation: food for space is no longer only an agency-led research activity, but an area in which firms are beginning to package greenhouse hardware, microbiome science, and orbital crop experimentation into commercial offerings.

AI should also be made explicit in the "food for space" dimension. In long-duration missions, food production will have to be carried out with limited crew time, delayed communication with Earth, strict resource constraints, and high reliability requirements. AI can support this environment by monitoring plant growth, detecting anomalies in closed-loop life-support systems, optimising water, nutrients, light, and energy use, and helping crews make autonomous decisions when real-time support from Earth is impossible. In this respect, space agriculture is not only a biological or engineering challenge; it is also a data and intelligence challenge. The same AI capabilities that support precision farming on Earth can be adapted to controlled-environment agriculture in orbit, on the Moon, or on Mars. This creates a direct bridge between "food for space" and "space for food" (Fazayeli et al., 2025).

Taken together, these cases show that "food for space" is evolving along three paths. First, it is becoming more biologically advanced, with growing interest in plant biotechnology, cultivated meat, algae, and controlled-environment systems. Second, it is becoming more systemically integrated, as food, air, water, and waste recycling are treated as one architecture rather than separate functions. Third, it is becoming more commercial, with companies and startups exploring how to turn space agriculture into a service, a platform, or a testbed for terrestrial innovation.

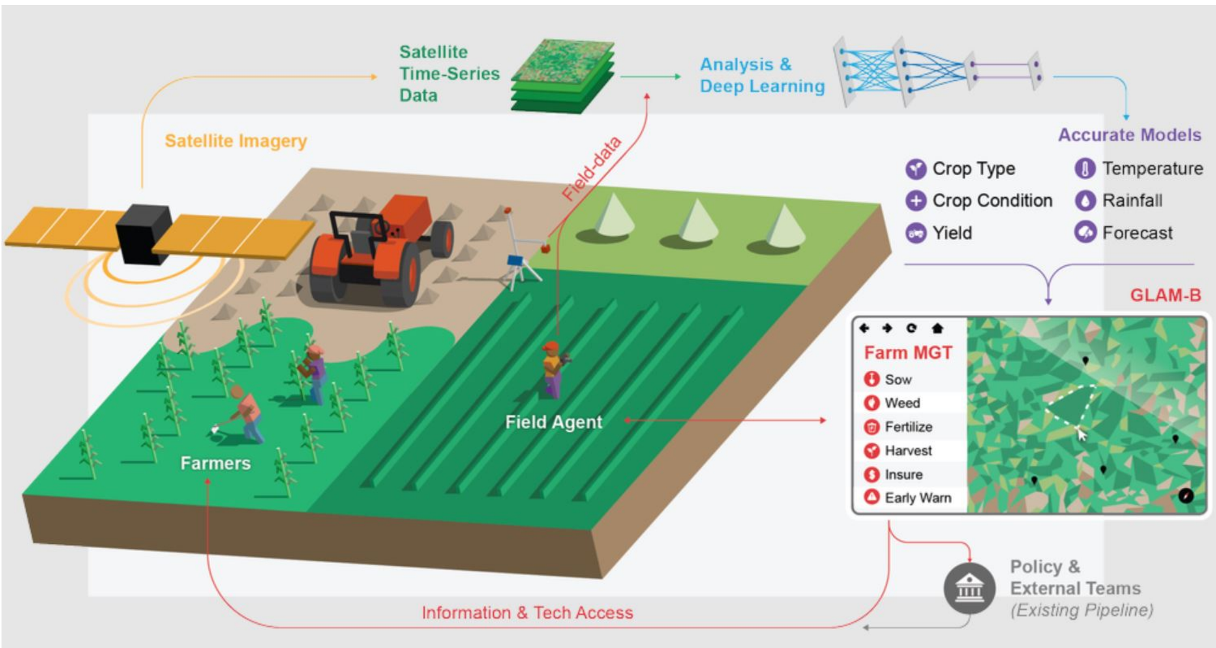
[3] https://ir.rdw.com/news-events/press-releases/detail/233/redwire-awarded-a-contract-from-astrobiome-space-to-launch

Space for food: how space technologies are transforming Earth's food systems

The reverse flow, from space to food on Earth, is already much more visible in operational terms. Copernicus (EUSPA, 2025), the European Union's Earth observation programme, states that agriculture is among the most promising markets for its impact, because satellite data help assess land use, crop conditions, yield forecasts, irrigation management, drought monitoring, seasonal mapping, and subsidy controls. In this sense, space infrastructure is not only an exploration asset; it is also a platform for everyday agricultural decision-making.

NASA Harvest[4] provides a similar but globally oriented example. NASA describes NASA Harvest as its Food Security and Agriculture Program, designed to enable the adoption of satellite Earth observations by public and private organisations to benefit food security, agriculture, and human and environmental resiliency in the United States and worldwide. NASA's Applied Sciences program adds that Earth observations help strengthen food security, market stability, and livelihoods, and that tools such as OpenET support water management by measuring evapotranspiration, the water lost from fields and crops. These are not abstract geospatial exercises; they are directly linked to irrigation, pricing, and risk management.

Figure 2 - Map of the NASA Harvest approach and programme.



(Source: https://www.nasaharvest.org/)

FAO has taken this logic further by explicitly linking geospatial technology and global food security. In 2025, FAO reported that a new UN publication recommended strengthening global capacities in satellite data for agriculture, improving interoperability, increasing international coordination on agriculture-focused missions, and creating a centralised imagery procurement hub to reduce duplication. FAO also emphasised that small-scale farmers and developing countries must be able to access and benefit from satellite data, rather than remaining on the margins of the space-data economy. This is an important

[4] https://www.nasaharvest.org/

policy insight: the value of space for food depends not just on sensor quality, but on access, governance, and institutional diffusion.

Commercial providers are now building business models around this opportunity. Planet says that its 3.7-meter imagery supports precision digital agriculture and pest detection at scale, allowing farmers and agronomists to monitor crop health and make more informed decisions. Planet also reports use cases in government agriculture monitoring and compliance, including the ability to cover all agricultural areas rather than only a small sample. e-GEOS, the Italian geospatial company, similarly markets AgriGeo as a solution combining geoinformation, Big Data, and AI to monitor cultivation status and improve agricultural sustainability and production processes. These cases show how space data are becoming an operational input for agribusiness rather than a niche research product.

The role of AI is especially important because satellite imagery alone does not generate actionable intelligence. AI connects remote sensing, weather data, soil data, farm records, supply-chain information, and market signals into decision-support systems. In "space for food", this means earlier detection of drought stress, pest pressure, disease risk, yield anomalies, irrigation needs, land degradation, and supply-chain vulnerability. These insights can support farmers, agronomists, insurers, food companies, and public agencies. In "food for space", the same AI logic can support autonomous crop monitoring, environmental control, and resource optimisation in closed-loop habitats. AI creates three bridges between the two perspectives: sensing, because it converts satellite or sensor data into readable signals; prediction, because it anticipates risks and yields; and optimisation, because it recommends actions under constraints of water, energy, land, crew time, or capital. In that sense, AI is not a separate layer at the end of the chain; it is the translation mechanism that turns observation into value and connects space technologies to practical food-system decisions.

The societal implications are significant and should be understood through four impact channels. First, satellite-enabled agriculture can strengthen food security by improving crop monitoring, yield forecasting, early-warning systems, and the targeting of emergency responses. Second, it can improve climate resilience by detecting drought stress earlier, reducing water waste, improving fertiliser targeting, monitoring land degradation, and supporting adaptation in climate-exposed regions. Third, it can support inclusion if satellite data and AI tools are made accessible to small-scale farmers, cooperatives, public agencies, and developing countries rather than remaining concentrated in advanced agribusiness platforms. Fourth, it raises questions of technological sovereignty because food systems increasingly depend on data infrastructures, cloud platforms, and AI models that a limited number of public or private actors may control. Concrete impact should be assessed not only through business revenues, but also through indicators such as yield-forecast accuracy, water savings, fertiliser-use reduction, farmer access, resilience to climate shocks, and the ability of public institutions to make evidence-based food-security decisions.

Innovation, business models, and the AI connection

The strategic significance of the food-space nexus lies in its dual-use and AI-enabled nature. Technologies developed for space habitats, such as closed-loop life-support systems, precision sensors, LED cultivation, robotics, and microgravity-compatible plant sciences, have immediate relevance for vertical farming, controlled-environment agriculture, and cultivation in deserts, remote areas, or climate-stressed regions. Conversely, digital agriculture platforms, Earth observation services, and AI analytics developed for terrestrial farming can inform the design of autonomous food systems in orbit, on the Moon, or on Mars. AI strengthens this dual-use logic because it allows knowledge to be transferred across contexts: data generated in space experiments can improve terrestrial models. Conversely, terrestrial agricultural datasets can train systems for future space habitats. The food-space nexus is best understood as a convergence industry in which biology, engineering, data science, and business model innovation reinforce one another.

A useful strategic lens for interpreting this convergence is the SEWA framework proposed by Giraldi (2025), which asks whether organisations should Start, Evolve, or Walk Away when facing opportunities in the space economy. Applied to the food-space nexus, "Start" (Giraldi & Rossi, 2026) refers to the creation of new ventures specifically designed around space-enabled food innovation, such as orbital agriculture platforms, space-food startups, cultivated-protein experiments, or AI-based satellite advisory services for agriculture. "Evolve" refers to existing food, agritech, aerospace, or data companies that adapt their capabilities to space-related markets, for example, by using Earth observation data, controlled-environment agriculture, or life-support technologies to develop new products and services. "Walk Away" is equally important because some projects may be technically fascinating but economically unsustainable, operationally too complex, or misaligned with regulatory and institutional conditions. The SEWA framework helps translate the food-space nexus from a broad innovation theme into a strategic decision-making process for entrepreneurs, incumbent firms, investors, and public institutions.

For businesses, the strategic recommendation is to evaluate opportunities through three practical criteria. First, firms should Start when the technology has a credible dual-market pathway, meaning that it can serve both space missions and terrestrial food-system needs. Examples include autonomous greenhouse modules, AI crop-monitoring platforms, cultivated-protein systems, and satellite-based advisory services. Second, firms should Evolve when they already possess relevant capabilities in food, agritech, aerospace, data analytics, logistics, or sustainability and can adapt them to space-enabled markets. This may involve integrating Earth observation into existing agronomic services, using space-inspired controlled-environment agriculture for premium or climate-resilient production, or building partnerships with agencies and startups. Third, firms should Walk Away when projects are mainly symbolic, technically fascinating but economically unclear, or dependent on public funding without a realistic route to customers. This decision discipline is important because the space-food nexus can attract attention, but business impact requires a clear value proposition, measurable performance, regulatory alignment, and scalable demand.

This convergence also suggests a clear educational and policy agenda. Policymakers should prioritise four actions. First, they should support interoperable and accessible satellite-data infrastructures for agriculture, especially for smallholders and developing countries that may otherwise remain excluded from the benefits of space-enabled services. Second, they should fund testbeds and challenge programs that connect controlled-environment agriculture, life-support systems, AI, and terrestrial climate-resilient food production. Third, they should use public procurement and public-private partnerships to reduce the gap between laboratory prototypes and scalable markets. Fourth, they should clarify rules on data governance, sustainability metrics, liability, and technological sovereignty, because strategic dependence on external satellite data or proprietary AI platforms can become a vulnerability for national food systems. ESA and NASA, through MELiSSA, NASA Harvest, Veggie, and the Deep Space Food Challenge, show that innovation in this area depends on collaboration across universities, agencies, startups, and industrial partners. Future research should examine not only the technologies themselves, but also the institutional conditions that allow them to scale responsibly.

Future research directions

Several research gaps remain open. First, there is still no settled framework for evaluating the economics of space-based food innovation: cost, resilience, sustainability, and mission performance are often measured separately, but not integrated into a common business-case model. Second, the space-food nexus would benefit from more comparative work across countries and institutional settings, especially between agency-led programs and private ventures. Third, AI deserves deeper study as both a technical and governance layer of the food-space nexus.

Future research should examine model accuracy, bias, explainability, data sovereignty, cybersecurity, and the distribution of benefits between large agribusiness firms, public agencies, startups, and smallholders. In the “food for space” dimension, research should study how AI can support autonomous food production, resource optimisation, and anomaly detection in closed-loop habitats. In the ”space for food” dimension, research should assess how AI-based satellite analytics affect farm-level decisions, insurance models, public food-security policy, and climate adaptation. This agenda is important because the impact of AI will depend not only on algorithmic performance but also on trust, access, institutional capacity, and governance.

A further dimension concerns social acceptance. Innovation in space food, space tourism, and long-duration human presence beyond Earth depends not only on technical feasibility but also on how people understand, trust, and symbolically frame space activities. Tasci, Fyall and Fu (2021) show that public attitudes toward civilian space travel are shaped by social representations, including information sources, anchors, and objectifications. Their findings suggest that scientific sources, credible organisations, and sustainability-oriented messages are more effective than purely spectacular or celebrity-driven narratives. This insight is relevant for the food-space nexus because future business models will need to address environmental concerns, public legitimacy, and the perceived social value of space-based innovation.

Conclusion

“Food for space” and “space for food” are two sides of the same transformation. Food for space is pushing science toward closed-loop life-support systems, controlled-environment agriculture, cultivated meat, and mission-ready nutrition for deep-space exploration. Space for food is already transforming Earth’s food systems through satellite observation, climate monitoring, digital agriculture, and AI-based decision support. The two dynamics reinforce one another: what is developed for space often spills over to Earth, while the tools used to feed Earth can help shape the future of human life beyond it. In that sense, the food-space nexus is not a peripheral curiosity of the space economy. It is one of its most promising aspects in terms of innovation, sustainability, and business development because it creates a concrete impact pathway. Space missions can serve as extreme testbeds for resource-efficient food production. At the same time, Earth observation and AI can help farmers, insurers, companies, and governments make better decisions under climate and market uncertainty. For managers, the key challenge is to identify business models that combine scientific credibility, operational value, and dual-market potential. For policymakers, the challenge is to ensure that space-enabled food innovation supports food security, climate resilience, inclusion, and technological sovereignty. The central message of the paper is that "food for space" and "space for food" should be governed and developed together as a dual system for sustainable innovation on Earth and beyond.

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