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Space agriculture and Indian agricultural research

S.K Rangari[1], M. K Rangari[2]

1 Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, 848 125 Bihar, India

2 Shri. Brijlal Biyani College of Arts, Commerce, and Science, Amravati, 444605 Maharashtra, India

Corresponding authors email: sagarrangari2@gmail.com

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Space agriculture is the conceptual and technical development of growing crops, fungi, and other edible biomass in extraterrestrial environments (spacecraft, Moon, Mars) to support long-duration human missions. As missions extend beyond the capacity for food resupply from Earth, space agriculture aims to create self-sustaining, bioregenerative life support systems that recycle waste, produce oxygen, and purify water. In order to support long-term human missions, space agriculture uses hydroponics, aeroponics, and specialised lighting to produce crops in controlled extraterrestrial settings (microgravity, moon/Mars). While traditional agriculture uses space technology, such as satellites, remote sensing, and precision farming, to maximise terrestrial crop yields, track droughts, and manage resources, it also makes it possible to produce food outside of Earth.

Space agriculture (Farming in space)

Techniques: Hydroponics (liquid nutrient solutions) and Aeroponics (nutrient mist) are used to eliminate the need for heavy soil, with plants grown in enclosed, artificial habitats.

Challenges: Microgravity impacts plant growth, while limited power and water necessitate highly efficient, closed-loop life support systems.

Successes: NASA's "Veggie" system on the International Space Station has successfully grown lettuce, cabbage, kale, and flowers, providing fresh food and mental health benefits for astronauts.

Key aspects of space agriculture and techniques

Hydroponics: Growing plants in nutrient-rich liquid solutions, removing the need for soil.

Aeroponics: Growing plants with roots suspended in the air, using mist to deliver nutrients.

Soil-like media: Using special substrates to support plant roots, often with slow-release fertilizers.

Systems and experiments

Veggie: A space garden on the International Space Station (ISS) that has grown lettuce, cabbage, kale, and flowers.

ISRO's CROPS: The Indian Space Research Organisation (ISRO) demonstrated the germination and growth of cowpea seeds in the Compact Research Module for Orbital Plant Studies.

Advanced plant habitat (APH): A larger, more sophisticated chamber on the ISS for agricultural experiments.

Environmental challenges

Microgravity: Plants face difficulty in nutrient uptake and root development without gravity.

Radiation & Lighting: High cosmic radiation and limited sunlight require specialized shielding and artificial, nutrient-specific LED lighting.

Atmosphere: Managing high levels and low in enclosed, pressurized environments.

Core components of hypothetical space agriculture

Controlled environment agriculture (CEA): Due to the lack of atmosphere and extreme temperatures, farming requires sealed, artificial habitats.

Hydroponics/aeroponics: Soil-free farming is preferred, where plants grow in nutrient-rich water or mist to avoid the challenges of managing soil in microgravity.

In-situ resource utilization (ISRU): Using local resources like lunar/Martian regolith, which is processed to remove toxins (like perchlorates) and supplemented with nutrients to create growing medium.

LED lighting: Specialized lighting systems that provide specific red, blue, and green light wavelengths to maximize photosynthetic efficiency.

Circular nutrient recycling: Technologies designed to turn waste into fertilizer, such as utilizing hyper-thermophilic bacteria to compost organic waste rapidly.

Key challenges and proposed solutions

Microgravity fluid dynamics: Water behaves unpredictably, tending to drown roots or dry them out.

Solution: NASA's "pillows" filled with clay substrate or specialized porous tubes that supply water through capillary action.

Lethal radiation: High levels of cosmic rays can damage plants.

Principal advantages of physical technology

Satellite infrastructure: To keep an eye on crop health, snow cover, and soil moisture, low-income countries deploy remote sensing satellites. This makes precision agriculture possible, which maximises productivity while cutting expenses by allowing farmers to apply fertiliser and water where it is needed.

Early warning systems: Predicting droughts and floods well in advance is made possible by space-based weather forecasting, which is essential for preventing famines in areas that are already at risk.

Technology for Indoor and Urban Farming: Space-based innovations, such as closed-loop waste recycling and LED-based vertical farming, are being modified for terrestrial application. These aid in food production in regions with limited land and water resources, such as dry regions.

Resilient crop varieties: Studies on cultivating plants in hostile space conditions (such as ISRO's cowpea tests) produce seeds that can withstand harsh climate change and temperatures on Earth.

Cost and accessibility

Affordability: Launches of ridesharing services and satellite miniaturisation (such as CubeSats) have reduced the cost of satellite deployment for developing countries.

International aid: To help developing nations obtain space data without requiring their own extensive space programs, organisations such as UNOOSA and FAO offer grants and technical assistance.

Efficiency: Although space programs are costly, they frequently account for less than 0.1% of a nation's GDP (India, for example), yet the agricultural data they produce can prevent billions of dollars' worth of lost crops.

Recent world progress

Space agriculture, which aims to develop sustainable, closed-loop life support systems, is evolving from experimental, small-scale research to a technology required for extended human space missions. Recent innovations include the use of nutrient-rich, soil-like media for growing vegetables and leafy greens on the International Space Station (ISS), the development of automated, AI-driven growth units (Interstellar Lab's Eden 1.0), and the successful germination of seeds in orbit (ISRO's CROPS mission).

Important worldwide advancements and current milestones

ISRO (India): A major advancement in microgravity plant growth was achieved in 2025 when cowpea (Lobia) seedlings were successfully germinated in space utilising the Compact Research Module for Orbital Plant Studies (CROPS). The Advanced Plant Habitat (APH) and 'Veggie' systems on the ISS are run by NASA (USA), which cultivates a variety of crops there, such as red Russian kale, kale, Chinese cabbage, lettuce, and zinnia.

Private sector and future stations: Sierra Space is creating cutting-edge growth technology for next commercial stations, while Vast, a private business, intends to launch Haven-1 in 2026 with the "Eden 1.0" plant growth unit built for microgravity.

International collaborations: In order to develop more durable crops for both Earth and space, the IAEA and FAO are studying the effects of cosmic radiation using seeds exposed to space conditions (Arabidopsis and Sorghum). Research on the use of lunar and Martian regolith (soil) for farming is growing. Experiments have shown that plant life can be supported by supplementing these materials with nutrients and, in certain situations, hydrogels.